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THE

AZOIC SYSTEM

AND ITS PROPOSED SUBDIVISIONS.

BY

J. D. WHITNEY AND M. E. WADSWORTH.

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PART I.

Synopsis of the Evidence on which the Rocks of the Azoic System have been variously grouped into Distinct Divisions by American Geologists.

In the following discussion the various regions where rocks of the Azoic System occur will be taken up and examined in a geographical order, beginning with that part of the North American continent where these rocks have their greatest development, and where, in course of a geological survey carried on continuously for more than forty years, a large portion of the material has been published which will here come under review. In order to prevent misunderstandings, and as an important assistance to those who may hereafter wish to make an independent examination of the questions here discussed, the exact language of the author quoted will be given in as much fulness as seems desirable, although this course must necessarily considerably increase the length of this paper.

CANADA.

Sir Wm. Logan, in the Report of Progress of the Canada Geological Survey for 1845–46 (pp. 40–51), described a series of rocks which he, following Lyell, called the "Metamorphic Series." This he divides into two divisions, one composed in general of "syenitic gneiss," the other of the same rock with intercalated bands of crystalline limestone. The relations of these to each other can be best expressed in Logan's own words: —

"To the south of the Mattawa and of the Ottawa in its continuation after the junction of the two streams, important beds of crystalline limestone become interstratified with the syenitic gneiss, and their presence constitutes so marked a character that it appears to me expedient to consider the mass to which they belong as a separate group of metamorphic strata, supposed from their geographical position and general attitude to overlie the previous rocks conformably. The limestone beds appear to be fewer at the bottom than at the top

of the group, but whether few or many, they are always separated by beds of gneiss which in no way differs either in constituent quality or diversity of arrangement from the gneiss lower down, except in regard to the presence of accidental minerals, the most common of which are garnets." (*l. c.*, pp. 41, 42.)

It is thus seen that his divisions are arbitrary and theoretical, both being, according to his statement, conformable and interlaminated with one another. As regards the origin of the "syenitic gneiss," or lower formations, he writes that they possess "an aspect inducing a theoretical belief that they may be ancient sedimentary formations in an altered condition." (*l. c.*, p. 40.) The lamination planes of the gneiss (?) appear to be taken without hesitation as planes of sedimentation. As before, theoretic belief, and not evidence, was the basis on which all was decided, and Logan never went beyond this.

Without adopting any theory of the origin of the rocks in question, it is sufficient simply to point out that, accepting Logan's own statements as true, the rocks might, so far as the published evidence goes, have originated in any way not *a priori* impossible. His evidence is valueless excepting so far as credit may be given to the skill he may at that time have possessed in distinguishing metamorphic sedimentary from metamorphic eruptive rocks.

Later he stated: —

"The succession of rocks in ascending order, ... after crossing sixty-three miles, ... occupied by the unbroken uniformity of the lower metamorphic, or syenitic gneiss, formation, is as follows: —

"1. Chloritic slates and conglomerates.

"2. Greenish sandstones.

"3. Fossiliferous limestones." (*l. c.*, p. 67.)

The chloritic slates and conglomerates were said to hold pebbles and boulders of the subjacent gneiss. The limestones were regarded from their fossils as being of the age of the Niagara. Mr. Logan says: —

"The facts that have as yet come within my observation in respect to these formations have not been sufficient to enable me to determine to my own satisfaction what their relations are in respect to conformability. That the limestones are unconformable with the slates appears almost certain, but it is not in my power to state with which the intermediate sandstones are conformable, if they are so with either, or whether they are unconformable with both; nor can I assert whether the slates are conformable with the gneiss." (*l. c.*, p. 69.)

We thus see that the chloritic slates and conglomerates, which later on lithological evidence were referred to the Huronian, were only shown to be older than the Niagara, their true age being unknown.

Logan in the Report of Progress for 1846–47 described the series on the north shore of Lake Superior in ascending order, as follows (*l. c.*, pp. 8–17) : —

"1. Granite and syenite.

"2. Gneiss.

"3. Chloritic and partially talcose and conglomerate slates.

"4. Bluish slates or shales, interstratified with trap.

"5. Sandstones, limestones, indurated marls, and conglomerates, interstratified with trap.

"The rock at the base of the series is a granite, frequently passing into a syenite by the addition of hornblende, but the hornblende does not appear to be often present wholly without the mica. . . . . The granite appears to pass gradually into a gneiss, which seems to participate as often of a syenitic as a granitic quality. . . . . The gneiss is succeeded by slates of a general exterior dark green colour, often dark-gray in fresh fractures, which at the base appear occasionally to be interstratified with beds of a feldspathic quality, of the reddish color belonging to the subjacent granite and gneiss. . . . . Some of the beds have the quality of a greenstone, others that of a mica slate, and a few present the character of quartz rock. Rising in the series, these become interstratified with beds of a slaty character, holding a sufficient number of pebbles of various kinds to constitute conglomerates. The pebbles seem to be of various qualities, but apparently all derived from hypogene rocks. . . . . The formations which succeed, rest unconformably upon those already mentioned. The base of the lower one [No. 4], where seen in Thunder Bay in contact with the subjacent green slates, presents conglomerate beds probably of no great thickness, composed of quartz pebbles chiefly, with a few of red jasper, and some of slate in a green arenaceous matrix, consisting of the same materials in a finer condition."

Reposing on the bluish slates (No. 4) are "sandstones, limestones, indurated marls and conglomerates interstratified with trap," and crowned by an enormous amount of volcanic overflow. No evidence is adduced to show that these two "volcanic formations" are unconformable with each other, but sufficient proof is cited to show that they are unconformable with the granite, gneiss, and chlorite slate. The volcanic formations are, however, regarded as being older than the Potsdam sandstone. (*l. c.*, p. 34.)

Logan further remarks : —

"The chloritic slates at the summit of the older rocks on which the volcanic formations rest unconformably, bear a strong resemblance to those met with in the upper part of Lake Temiscamang on the Ottawa, and it appears probable they will be found identical." (*l. c.*, p. 34.)

Logan evidently held that the greenish slates (No. 3) were conformable to and continuous with the underlying gneiss, one rock passing into the other; while the conglomerates observed were not at the base of the slates, but quite high in the series. (Geol. of Canada, 1863, pp. 52–55, 64.) Dr. Hunt's language in his "Azoic Rocks" (p. 68) implies that Logan found a different relation between the gneiss and slate, — namely, unconformability with the conglomerate at the base.

Mr. Alexander Murray in the same report (1846–47) states that the rocks in the basin of the Kamanistiquia River are granite, syenite, gneiss, micaceous and chloritic schist, overlain by blackish argillaceous slates with associated trap.

Of the first series he says: —

"Where they make their appearance at the lower end of the portage, the character of the rock is a red or in some instances a whitish massive syenite, which passes gradually into a gray gneissoid syenite, dipping at a high angle N. N. W. Resting conformably on the gneiss, there occurs a series of dark greenish blue or greenish black altered slates, the one rock passing almost imperceptibly into the other. . . . . Towards the bottom near the junction with the syenitic portion, the slates are of a dark bluish and occasionally of a brownish color. They appear to be highly altered."

Of the black argillaceous slates Mr. Murray says: —

"The base of this formation . . . . was observed on the Kamanitiquia near the Grand Falls. Its immediate junction with the rock on which it reposes was concealed from view, but appears to be indicated by the position of a small lake or pond, occurring just below the second portage, and the marshy ravines which run from it in the direction of the strike on each side. The slates visibly reach to within a short distance of the pond, probably brought into place against the syenite by a dislocation." (*l. c.*, pp. 51–53.)

The syenite and gneiss afterwards were assigned to the Laurentian, and the greenish blue or greenish black slates to the Huronian. Hence we see that at the only contact known for many years of the Laurentian and Huronian both series were conformable, *passing almost imperceptibly into one another*. Also, that near the junction the slates were highly altered. (Geol. of Canada, 1863, p. 64.) These facts are not mentioned by Dr. Hunt in his account of this report. (Azoic Rocks, pp. 68, 69.) It is, however, to be kept in mind, that at this time, as also when the Huronian was named and for some years later, Nos. 4 and 5, or the black slates, sandstones, traps, conglomerates, etc., constituting the copper-bearing series (Keweenawan, but really Potsdam) were held to be the exact equivalents of the schists and slates (Huronian) north of

Lake Superior, while the above greenish slates (No. 3) were not separated from the preceding rocks (Nos. 1 and 2) until many years later. (See Am. Jour. Sci., 1852, (2) XIV. 224–229; 1857, XXIII. 305–314; Azoic Rocks, pp. 71, 72, 80.)

In the Report of Progress for 1847–48, Mr. Murray gives some account of the sequence of the rocks on the islands and northern shore of Lake Huron.

"The older groups observed consist, firstly, of a metamorphic series, composed of granitic and syenitic rocks, in the forms of gneiss, mica slate, and hornblende slate; and, secondly, of a stratified series composed of quartz rock or sandstones, conglomerates, shales and limestones, with interposed beds of greenstone;"

succeeded by fossiliferous formations, i. e. Potsdam sandstone, etc. Certain of the conglomerates of the second series are said to contain pebbles and boulders of syenite, but beyond this nothing is advanced to show the relations of this to the granitic and syenitic rocks, the two series not being seen in contact. The relation of the fossiliferous formations to the preceding series was shown clearly enough, the separation being a marked one. (*l. c.*, pp. 107–113.)

Mr. Murray further says:—

"On a cluster of small islands . . . . Granite, [lithologically like the Laurentian,] was found breaking through the quartz-rock. . . . . The colour of the rock was red. On one of the islands, quartz-rock beds on opposite sides of the granite were observed to dip in opposite directions, north on the north side and south on the south side, at an angle of 70° or 80°; and in another of the islands the quartz-rock and granite were seen in juxtaposition, the former reclining on the latter. In this case the quartz rock was traversed by several trap dykes running slightly oblique to the strike, while granitic veins ran transversely through the whole, and were continued through a main body or nucleus of granite, the one granite being distinguishable from the other, notwithstanding the red color of both, by the finer texture of the veins." (*l. c.*, pp. 112, 113.)

In a "Report on the North Shore of Lake Huron," under date of December 29, 1848, Mr. Logan gives some account of the second series described by Mr. Murray, and states:—

"The series of rocks occupying this country from the connecting link between Lakes Huron and Superior to the vicinity of Shebawenahning, a distance of 120 miles, with a breadth in some places of ten, and in others exceeding twenty miles, it appears to me, must be taken as belonging to one forma-

tion ; on the west it seems to repose on the granite, which was represented in my report on Lake Superior as running to the east of Gros Cap, north of Sault Ste. Marie ; on the east the same supporting granite was observed by Mr. Murray north of La Cloche, between three and four miles in a straight line up the Rivière au Sable, ... and again, about an equal distance up another and parallel tributary, ... in both cases about ten miles from the coast. . . . . In respect to the geological age of the formation, the evidence afforded by the facts collected last year by Mr. Murray . . . . is clear, satisfactory, and indisputably conclusive, ... successive formations of the lowest fossiliferous group of North America, were each in one place or the other found, in exposures divested of all vegetation, resting in unconformable repose, in a nearly horizontal position, upon the tilted beds, and undulating surface of the quartz rock, and its accompanying strata, filling up valleys, overtopping mountains, and concealing every vestige of dykes and copper veins. . . . . The chief difference in the copper-bearing rocks of Lakes Huron and Superior, seem to lie in the great amount of amygdaloidal trap present among the latter, and of white quartz rock or sandstone among the former. But on the Canadian side of Lake Superior there are some considerable areas, in which important masses of interstratified greenstone exist without amygdaloid, while white sandstones are present in others, as on the south side of Thunder Bay, though not in the same state of vitrification as those of Huron. But notwithstanding these differences, there are such strong points of resemblance in the interstratification of igneous rocks, and the general mineralized condition of the whole, as to render their positive or proximate equivalence highly probable, if not almost certain ; and the conclusive evidence given of the age of the Huron, would thus appear to settle that of the Lake Superior rocks, in the position given to them by Dr. Houghton, the late State Geologist of Michigan, as beneath the lowest known fossiliferous deposits, a position which, as will be seen by a reference to the Report of Progress I had the honor to submit to your Excellency in 1846, appeared to me to derive some support from evidences on the Canadian side of Lake Superior itself." (*l. c.*, pp. 8, 9, 19, 20.)

In this is to be seen one of the attempts to decide geological age by lithological evidence, applied to rocks at great distances from one another, — a failure, in this case at least, as will be seen farther on. One of the writers has pointed out elsewhere that the statements in this report and in that for 1846–47 (p. 34) regarding Dr. Houghton's views are erroneous. (Bull. Mus. Comp. Zöol. 1880, VII. (Geol. Series I.) 83.) The views which Logan held regarding the age of the copper-bearing rocks of Lake Superior at the time of the publication of the report from which quotations have just been made, were published later in several papers. (Bull. Soc. Geol. France, 1849–50, (2) VII. 207–209. Report Brit. Assoc. Adv. Sci., 1851, Trans. Sec., pp. 59–62. Am. Jour. Sci., 1852, (2) XIV. 224–229.) In these publications the copper-bearing

rocks of Lake Huron, and therefore those of Lake Superior, were regarded as being of Cambrian age.

In the Report of Progress for 1848–49, Mr. Murray again reported on the region north of Lake Huron. He arranges the rocks along the Spanish River into two series: the *granitic or metamorphic group*, and the *quartz rock group*. The first group "appeared to rise from beneath the rocks of the second group in two different localities," but no evidence seems to have been found to show the relations of the two supposed formations except the finding of pebbles of granite or syenite in some of the conglomerates of the second group. The rocks of the first group were said to be granite or syenite, except the following: —

"A gneissoid structure was observed on one or two occasions, but it was for the most part obscure and ill-defined, being perceptible rather in a longitudinal arrangement of the constituent minerals, than in conspicuous beds of different quality." (*l. c.*, pp. 36–42.)

In the Report of Progress for 1849–50, a tract of country on the St. Lawrence River, between Bay St. Paul and Murray Bay, was described. Here the metamorphic group, consisting of gneiss, was overlain by white quartz rock (Potsdam sandstone). (*l. c.*, pp. 8–10.) In the Report for 1851–52, the *metamorphic or gneissoid group* is likewise said to be overlain by Potsdam sandstone in the country between Beauharnois and the Rivière du Nord. (*l. c.*, p. 6.)

In the Quarterly Journal of the Geological Society (Vol. VIII., 1852, p. 210), Mr. Logan states regarding the rocks north of Lake Huron: —

"On Lake Huron the Lower Silurian group rests unconformably upon a siliceous series with only one known band of limestone, of about 150 feet thick, with leaves of chert in abundance, but as yet without discovered fossils. This series is supposed to be of the Cambrian epoch. It comprehends the copper-bearing rocks of that district, and with its igneous interstratified masses has a thickness of at least 10,000 feet. The gneissoid group, of which mention is made, is probably still older than this. Its conditions appear to me to make it reasonable to suppose that it consists of aqueous deposits in an altered state."

In the Report for 1852–53, but published in 1854, Mr. Logan writes: —

"The name which has been given in previous Reports to the rocks underlying the fossiliferous formations in this part of Canada is the Metamorphic series, but inasmuch as this is applicable to any series of rocks in an altered condition, and might occasion confusion, it has been considered expedient to apply to them for the future, the more distinctive appellation of the Laurentian

series, a name founded on that given by Mr. Garneau to the chain of hills which they compose. The geological formations which underlie the district in ascending order would thus be as follows : —

"1. Laurentian series.

"2. Potsdam sandstone," etc. (*l. c.*, p. 8.)

It will thus be seen that when the name Laurentian was thus proposed, it was the exact equivalent of the Azoic of Foster and Whitney proposed four years before.

In "A Sketch of the Geology of Canada," by Dr. Hunt, occurs the first mention of the Huronian system as such.

"The shores of Lakes Huron and Superior offer a series of schists, sandstones, limestones and conglomerates interstratified with heavy beds of greenstone, and resting unconformably upon the Laurentian formation. As these rocks underlie those of the silurian system, and have not as yet afforded any fossils, they may probably be referred to the Cambrian system (lower Cambrian of Sedgwick.). . . . . This Huronian formation is known for a distance of about 150 leagues upon Lakes Huron and Superior, and everywhere offers metalliferous veins, which have as yet been very little explored." (Canada at the Universal Exhibition of 1855, pp. 427, 428.)

In the same paper Dr. Hunt says of the Laurentian system : —

"The rocks of this system are, almost without exception, ancient sedimentary strata, which have become highly crystalline." (p. 421.)

So far as we are able to find in the Reports of the Canada Geological Survey no evidence was advanced to prove this position ; it was a purely theoretic assumption, as Logan states (*ante*, pp. 331, 332). Dr. Hunt also declares that the Huronian on the shores of Lakes Huron and Superior rests unconformably upon the Laurentian formation. This too was a theoretical belief instead of an observed fact, so far as the Reports bore evidence (p. 427), except in the case of the Lake Superior copper-bearing rocks (Keweenawan, Potsdam), at that time regarded as being the equivalent of the schists (Huronian) north of Lake Huron. (See Azoic Rocks, pp. 71, 72 ; also *ante*, pp. 334, 335.)

Of the chlorite schists in the valley of Lake Temiscaming it is written : —

"The chloritic schists probably correspond to the Huronian rocks, but it is difficult to fix the age of the sandstones which are destitute of fossils." (*l. c.*, p. 447.)

The first mention of the Huronian formation by name, found in the Reports of Progress of the Canada Geological Survey, is in Mr. Murray's Report for 1854, under date of June 11, 1855, (p. 125,) as follows : —

"Among the boulders on Lake Nipissing, many were observed to be of a slate conglomerate, and they were frequently of very great size; in their aspect and general character these have a very strong resemblance to the slate conglomerate of the Huronian series, from which in all probability, they are derived."

The next mention is in the Report for 1855, dated March 1, 1856, p. 134: —

"The pebbles and boulders of metamorphic rocks which abound in the gravel and clay deposits, and are numerously scattered over the surface, are clearly derived from the Laurentian and Huronian formations on the north shore of Lake Huron."

In the Report for 1856 (March 1, 1857, pp. 168, 172) it is stated: —

"The rocks of the region explored during the season, embrace two of the oldest recognized geological formatios, the Laurentian and Huronian. . . . . The difference in lithological character between the two formations was always sufficiently apparent, but though both were frequently found at short distances apart, the immediate point of contact was always obscure; and a mass of greenstone of rather coarse grain was usually the first intimation of the proximity of the higher rocks. . . . . Whether this greenstone is the result of an overflow contemporaneous with the upper formation, or an eruptive mass intruded at a later period, has not yet been ascertained."

Regarding the *hypersthene rock* which has since been set apart as the Upper Laurentian or Norian Series, Dr. Hunt in his Report for 1854 (April 1, 1855, p. 374) states: —

"The rocks about to be described belong to the crystalline strata of the Laurentide mountains, and occur, as far as yet observed, in close association with the crystalline limestones, which alternate with the gneissoid and quartzose rocks of the formation."

In Dr. Hunt's Report for 1856 (April 1, 1857, p. 451, see also Philosophical Magazine, 1855, (4) IX. 354, 355), it is written concerning the same rocks: —

"In the Report for 1854 I have described at some length a class of stratified felspathic rocks, which form an important part of the Laurentian series, and are associated with the calcareous and magnesian deposits of that ancient formation."

The Reports here referred to from 1853 to 1856 were not published until 1857.

The division of the Azoic rocks into Laurentian and Huronian, and Logan's view that the copper-bearing rocks of Lake Superior were of

the same age as the Huronian rocks of Lake Huron, were opposed the same year by one of the present writers in the May number of the American Journal of Science (1857, (2) XXIII. 305–314). He also pointed out Logan's violation of the law of priority in appropriating the term Laurentian from Desor.* It was there shown that the reason Logan had for separating the Huronian from the other Azoic rocks was his (Logan's) belief that the copper-bearing rocks (Potsdam) of Lake Superior were the same as the Azoic schists north of Lake Huron: hence, as the copper-bearing rocks of Lake Superior rested unconformably on Azoic granites, etc., therefore the Lake Huron rocks must. Later, Logan abandoned his premises, but did not, however, give up his conclusion. (See Hunt, Azoic Rocks, p. 80.)

In the Proceedings of the American Association for the Advancement of Science (August, 1857, pp. 44–47), Mr. Logan made some statements regarding "the division of the Azoic Rocks of Canada into Huronian and Laurentian," the chief of which we reproduce here: —

"The sub-Silurian Azoic rocks of Canada occupy an area of nearly a quarter of a million of square miles. Independent of their stratification, the parallelism that can be shown to exist, between their lithological character and that of metamorphic rocks of a later age, leaves no doubt on my mind that they are a series of ancient sedimentary deposits, in an altered condition. . . . . So early as the year 1845, as will be found by reference to my report on the Ottawa district (presented to the Canadian government the subsequent year), a division was drawn between that portion which consists of gneiss and its subordinate masses, and that portion consisting of gneiss interstratified with important bands of crystalline limestone. I was then disposed to place the lime-bearing series above the uncalcareous, and although no reason has since been found to contradict this arrangement, nothing has been discovered especially to confirm it. . . . . In the same report is mentioned, among the Azoic rocks, a formation occurring on Lake Temiscaming, and consisting of silicious slates and slate conglomerates, overlaid by pale sea-green or slightly greenish-white sandstone, with quartzose conglomerates. The slate conglomerates are described as holding pebbles and boulders (sometimes a foot in diameter) derived from the subjacent gneiss, the boulders displaying red feldspar, translucent quartz, green hornblende, and black mica, arranged in parallel layers, which present directions according with the attitude in which the boulders were accidentally inclosed. From this it is evident that the slate conglomerate was not deposited until the subjacent formation had been converted into

* This paper of Prof. Whitney's, in common with some others, was accidentally omitted in Mr. Wadsworth's "List of Papers" appended to the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," although reference was made to it in the text. (See also Canadian Journal, 1857, (2) II. 302.)

gneiss, and very probably greatly disturbed; for while the dip of the gneiss, up to the immediate vicinity of the slate conglomerate, was usually at high angles, that of the latter did not exceed nine degrees, and the sandstone above it was nearly horizontal. In the Report transmitted to the Canadian government in 1848, on the north shore of Lake Huron, similar rocks are described as constituting the group which is rendered of such economic importance, from its association with copper lodes. This group consists of the same silicious slates and slate conglomerates, holding pebbles of syenite instead of gneiss, similar sandstones, sometimes showing ripple marks, some of the sandstones pale-red green, and similar quartzose conglomerates, in which blood-red jasper pebbles become largely mingled with those of white quartz, and in great mountain masses predominate over them. But the series is here much intersected and interstratified with greenstone trap, which was not observed on Lake Temiscaming. . . . . The group on Lake Huron we have computed to be about 10,000 feet thick, and from its volume, its distinct lithological character, its clearly marked date posterior to the gneiss, and its economic importance as a copper-bearing formation, it appears to me to require a distinct appellation, and a separate color on the map. Indeed, the investigation of Canadian geology could not be conveniently carried on without it. We have, in consequence, given to the series the title of Huronian. A distinctive name being given to this portion of the Azoic rock, renders it necessary to apply one to the remaining portion. The only local one that would be appropriate in Canada is that derived from the Laurentide range of mountains, which are composed of it from Lake Huron to Labrador. We have, therefore, designated it as the Laurentian series." (See also Canadian Journal, 1857, (2) II. 439–442; Canadian Nat. and Geol., 1857, II. 255–258.)

The logic of the last few sentences will appear to be of a somewhat peculiar character, when it is remembered that the name "Laurentian" had been adopted some two years before the name "Huronian" was used, and some four years before Mr. Logan's paper was read.

As we have pointed out before, the age of the Lake Temiscaming slates was unknown.

In the same Proceedings Mr. Logan published a paper "On the Probable Subdivision of the Laurentian Series of Rocks of Canada." Some limestone and associated labradorite rocks he would set apart, but does not propose any name for them. This division seems to be a local one based on lithological characters, as no evidence was advanced to show that this formation was not conformable with the remainder of the Laurentian, as it had been stated to be before. (Proc. Am. Assoc. Adv. Sci., 1857, XI. 47–51; Canadian Journal, 1858, (2) III. 1–5; Canadian Nat., 1857, II. 270–274.)

Dr. J. J. Bigsby, in 1862, regarded the Huronian as distinct from the

Cambrian, and intimately related to the Laurentian, giving among his reasons its marked similarity, lithologically, to the Laurentian, and the conformity of the Laurentian and Huronian; and stating that in the only place north of Lake Superior where the two systems have been seen in contact, they were found conformable. (Quart. Jour. Geol. Soc., 1863, XIX. 36–52.)

Two other localities spoken of by Dr. Bigsby were hypothetical, not actual observed contacts, as he supposed. (See Report on the North Shore of Lake Huron, 1849, pp. 8, 9; Report of Progress, 1848–49, p. 36.)

In the Report on the Geology of Canada, 1863, the so-called gneisses of the Laurentian series are assumed to be stratified, and although the acknowledgment is made that the supposed beds "when thick, which they usually are, might on first inspection be mistaken for intrusive igneous instead of altered sedimentary masses." That they are really sedimentary is supposed to be shown by the minerals being obscurely arranged in parallel lines "conformable with the more distinctly banded portion of the strata." (*l. c.*, p. 23. See also p. 587.)

In fact Mr. Logan states: "The rocks which compose the Laurentian mountains were shown by the Geological Survey, in 1846, to consist of a series of metamorphic sedimentary strata, underlying the fossiliferous rocks of the Province." We have pointed out that nothing of the kind was shown by the Survey; but that there was only an announcement of "a theoretic belief that they may be ancient sedimentary formations in an altered condition." (Geol. Survey of Canada, 1845–46, p. 40, 1863, p. 22; Azoic Rocks, p. 66; *ante*, p. 332.)

Mr. Logan further states, that it is difficult north of Lake Huron to distinguish the Laurentian gneiss from an intrusive granite. (Geol. of Canada, 1863, p. 61.)

Regarding the relation of the Huronian to the Laurentian nothing that can be called evidence is advanced, except in one place; but, as usual, some general assertions are made. The following extract will give an idea of what was actually known of the relations of the two formations, with the exception to be mentioned later.

"In that part of the country on the north shore of Lake Huron which lies between Mississagui and St. Mary Rivers, where the Huronian series has been more completely examined than elsewhere, the immediate contact of the gneiss with the overlying rocks has not been observed. On the coast line between the Mississagui and Thessalon Rivers, a distance of about twenty-five miles, the gneiss extends from within about four miles of the former to within about

the same distance from the latter; but it is very much disturbed by intrusive granite and greenstone, and, although there are great exposures of rock, it is very difficult to make out how the stratified portions are related to one another. The gneiss extends to the vicinity of a small stream about a mile and a half above Les Grandes Sables, and what is supposed to be the lowest Huronian mass of that part occurs about half a mile above the stream. It consists of a grey quartzite which abuts against one mass of gneiss and runs under another, and appears to be much broken by and entangled among the intrusive rock; but judging from a transverse measure in one part, its thickness would not be far from 500 feet." (*l. c.*, p. 55.)

It would seem that here the Huronian was found abutting against and underlying the Laurentian gneiss (granite). In none of the sections given do the conglomerates in the Huronian appear to lie at the base of the formation, but at varying heights in the series.

The exception referred to above is this: under the head of "Contact of Laurentian and Huronian Rocks," it is stated that in the upward navigation of the Kaministiquia River

"the first development of the Laurentian series occurs at the second portage, about half a mile above the Grand Falls. At the lower end of the portage, where the series makes its appearance, the rock resembles a massive syenite, in some parts red and in others whitish, but is probably a hornblendic gneiss in which the lamellar arrangement of the constituent minerals is obscure, as the rock gradually passes into such a gneiss. Resting on it conformably there occurs a series of dark greenish-blue or greenish-black slates, the one rock passing almost imperceptibly into the other. The section occupies upwards of a quarter of a mile on the river bank, and at the upper end of it, as well as at the head of the portage, the dip is N. 54° E. . . . . At each rapid part of the river above the Grand Falls there is a greater or less development of these rocks, most frequently presenting the more distinctly stratified part of the gneiss. The best exposure of the slates is at the Three Discharges, about four miles above the Grand Falls, where the rocks are observed to pass from the gneiss to the slate. . . . . Towards the bottom, near the junction with gneiss, the slates are of a bluish and occasionally of a brownish color." (*l. c.*, pp. 64, 65.)

It would then appear that Huronian in the only localities, except one problematical one (*l. c.*, pp. 52–54, 703), in which it had been seen in contact with the Laurentian, was conformable with and passed almost imperceptibly into, or else underlaid, the Laurentian.

An intrusive granite is said to occupy

"a considerable area on the coast of Lake Huron, south of Lake Pakowagaming. It there breaks through and disturbs the gneiss of the Laurentian series, and

forms a nucleus from which emanates a complexity of dykes, proceeding to considerable distances. As dykes of a similar character are met with intersecting the rocks of the Huronian series, the nucleus in question is supposed to be of the Huronian age, as well as the greenstone dykes which are intersected by it." (*l. c.*, p. 58.)

Mr. Logan seems in this report to have abandoned the idea that the copper-bearing rocks of Lake Superior were of the same age as those north of Lake Huron, except in some minor districts classed as Huronian; for he calls the Huronian formation the Lower Copper-bearing rocks, and places the others as the Upper Copper-bearing rocks. These latter rocks he divides into two groups, and writes of their age as follows: —

"The precise age of the upper copper-bearing rocks of Lake Superior is a question attended with some difficulty. Mr. Whitney appears disposed to regard the whole series from the summit of the sandstones of Sault Ste. Marie to the base of the Kaministiquia slates as one group equivalent to the Potsdam formation; but the suspicion of a want of conformity between the Sault Ste. Marie sandstones and the trappean rocks beneath, would induce us to separate the two. . . . . The affinities of the red sandstone of Sault Ste. Marie would thus appear to bring it into the position of the Chazy rather than the Potsdam formation; and if this were established, the copper-bearing portion of the Lake Superior rocks might reasonably be considered to belong to the Calciferous and the Potsdam formations." (*l. c.*, pp. 84–86.)

This is an abandonment of the attempt to determine the age of the Lake Superior copper-bearing rocks by lithological characters only, and, so far as Mr. Logan is concerned, a removal of those rocks from the Azoic series.

In the supplement to this report the labradorite rocks occurring in the Laurentian series are thought to unconformably overlie the lower portion of the Laurentian formation, cutting out some limestone bands. The contacts were not seen; but, as the labradorite rocks were assumed to be sedimentary, this replacement of the limestone was held to prove their unconformability with the Laurentian. (*l. c.*, pp. 837–839.)

The same year Dr. Hunt remarked: —

"The so-called granites of the Laurentian and Lower Silurian appear to be in every case indigenous rocks; that is to say, strata altered *in situ*, and still retaining evidences of stratification. The same thing is true with regard to the ophiolites and the anorthosites of both series; in all of which the general absence of great masses of unstratified rock is especially noticeable." (Am. Jour. Sci., 1863, (2) XXXVI. 226.)

In the Report of Progress from 1863 to 1866 (pp. 127–129), Mr. Thomas Macfarlane describes the contact of some supposed Huronian with Laurentian rocks as follows : —

"The manner in which these Huronian rocks adjoin those of the Laurentian series may be observed on the north shore between Michipicoten Harbour and Island. I paid some attention to that point of junction which lies to the west of Eagle River, the precipitous cliffs to the east of which, consist principally of diabase schist and greenstone slate. A few miles to the west of these cliffs, and at a point bearing N. 29° 5° E., from the east end of Michipicoten Island, the Laurentian granite is penetrated by enormous dykes of dense basaltic greenstone (having the peculiar doleritic glitter when fractured) which contain fragments of granite. This greenstone is also seen in large masses, which can scarcely be called dykes, overlying the granite, and enclosing huge masses of that rock, one of which I observed to be cut by a small vein of the greenstone. From this point to Eagle River, those two rocks alternately occupy the space along the shore, seldom in such a manner as to shew any regular superposition of the greenstone on the granite, but almost always more or less in contact with each other. The greenstone, however, becomes more frequent towards the east, and at Eagle River it has almost replaced the granite, and assumed a lighter colour, and an irregular schistose structure. The strike of these schists is at places quite inconstant ; they wind in all directions, and what appear at first sight to be quartz veins, accompany their contortions. On closer inspection, however, of the largest of these, they are seen to be of granite, but whether twisted fragments of that rock, or really veins of it, is at first glance very uncertain. Observed superficially they have the appearance of veins, but they do not preserve a straight course, and bend with the windings of the enclosing schist. They often thin out to a small point and disappear, and, a few feet or inches further on in the direction of the strike, reappear and continue for a short distance. Sometimes a vein thins out at both ends, and forms a piece of granitic material of a lenticular shape, always lying parallel with the stratification. Although they are seldom or never angular, they can scarcely be regarded otherwise than as fragments whose shape has been modified by contact with the greenstone. . . . . There would seem to be only two ways of explaining the phenomena above described. Either the granite forms veins, penetrating the schistose greenstones, in which case the latter are the older rocks ; or it is in the form of contorted fragments, in which case the inclosing rocks may be of eruptive origin. The latter supposition seems to be most in harmony with the facts stated, and with what is known as to the relative ages of the Laurentian and Huronian rocks. I may here remark that in Foster and Whitney's Lake Superior Report (Part II., pp. 44 and 45) analogous phenomena are described, but the exactly opposite conclusion is arrived at, viz.: that the granite is in veins, and forms the newer rock. Similar relations are observed at other points of junction on the north shore, and the peculiar breccia, described among the greenstones above mentioned, occurs at no great distance from one

of these. It is remarkable that the greenstone found associated with it is also basaltic, and this is also the case with the trap occurring at the junction of the two formations in the northeast corner of Bachewahnung Bay. Here it is finer grained, but still possesses the glittering fracture of basaltic greenstone. The Laurentian rock is a highly granitic gneiss, and pieces of it are enclosed in the black greenstone, which at one place seems to underlie the granite. A reddish-grey felsitic rock, with conchoidal fracture, is observed at the point of junction. Eastward from it banded traps occur, striking N. 55° W., together with greenstone breccia and conglomerate of the characters already described. On ascending the hills behind this point a breccia is observed, of which the matrix is greenstone, and the fragments granite. The lines of junction between the Laurentian and Huronian series, and between these and the Upper Copper-bearing rocks, so far as observed during the exploration, are given on the accompanying map. With regard to the succession of the strata, I found myself as much at a loss among the irregularly schistose Huronian greenstones, as among the gneissoid granites of the Laurentian."

It seems almost incredible that a geologist, who professed to be a lithologist, should have been unable to ascertain the relations and relative age of these rocks, when so many excellent exposures were observed as he states. His observations show clearly that both formations here are eruptive, and of the same geological age.

In the *Esquisse Géologique du Canada* (Paris Exhibition of 1867, p. 10) the Huronian is said by Dr. Hunt to repose unconformably on the Lower Laurentian formation, and probably also on the Upper Laurentian. It is to be remembered, however, that at the locality on the Kaministiquia River, in which the Huronian had been seen in contact with the Laurentian, the two were found to be conformable. (Geology of Canada, 1863, pp. 64, 65.)

In the same paper (p. 5) Dr. Hunt claimed that the Laurentian comprised two distinct series of rocks, of which one reposed with discordant stratification on the other: these he calls the Lower Laurentian and Upper Laurentian, or Labradorian.

In the Report of Progress for 1866–69, Mr. James Richardson reports, that in the region north of the lower St. Lawrence River

"the Laurentian gneiss sometimes has little appearance of stratification; the strike is generally north and south, with dips often approaching vertical. The strata are all more or less broken, contorted and faulted. The labradorite rocks rest unconformably on the Laurentian; they generally strike nearly east and west, and dip at comparatively moderate angles, with little or no appearance of contortion or disturbance. . . . . The reddish quartzose granitoid rock of the Laurentian is again met with, offering no evidence of stratification; and in one place is seen to be distinctly overlaid by a patch, only a few yards

square, of labradorite-rock, shewing considerable varieties in character, and clearly stratified." (*l. c.*, pp. 305–307.)

Mr. Richardson's work failed to prove his conclusions, as the rocks were not shown to be sedimentary.

In 1868 Mr. J. Marcou wrote regarding the Laurentian and Huronian formations: —

"The Laurentian system is composed of the Lower Taconic, to which are added all the unstratified crystalline rocks forming the centre of the Laurentine Mountains, such as granite, syenite, diorite and porphyry, mixing together strata and eruptive rocks, an attempt which was unexpected from a stratigraphical geologist. His Huronian system is formed of a mixture of the St. Albans group of the Upper Taconic, with the Triassic rocks of Lake Superior, the trap native-copper bearing rocks of Point Keeweenaw, and the dioritic dyke containing the copper pyrites of Bruce mine on Lake Huron." (Proc. Bost. Soc. Nat. Hist., 1861, VIII. 246, 247.)

In the Report of Progress for 1870–71, Mr. Robert Bell points out a case of an apparently conformable junction of the Huronian and Laurentian rocks. He remarks: —

"From the mouth to the sixteenth portage . . . . the river [White River] runs entirely upon greyish and reddish gneiss, mostly of a massive granitic character [Laurentian], striking W. S. W., and dipping northward at angles varying from 30° to 80°. It is occasionally interstratified with bands of dark hornblendic schist and very light grey gneiss. Fine dark green hornblendic schists [Huronian], having the same strike, occur between the sixteenth portage and the outlet. . . . . Similar schists [Huronian], with bands of gneiss, appear to rest conformably upon the massive gneisses at a short distance north of the river, all the way from Natamasagami Lake to the mouth (28 miles)." (*l. c.*, p. 345.)

Of another locality Mr. Bell, in the Report for 1871–72, states: —

"Towards the end of the above twenty miles, bands of gneiss become interstratified with the schists, and just at Martin's Falls the latter have become entirely replaced by red and grey gneiss, apparently shewing a conformable passage from the Huronian into the Laurentian rocks. What appeared to be a similar blending of these formations was noticed last year in the neighborhood of White Lake." (*l. c.*, p. 110.)

In the Report of Progress for 1872–73, Mr. Bell again states, regarding the rocks northwest of Lake Superior: —

"As mentioned in the present and in my previous reports on this region, the Huronian rocks appear to succeed the Laurentian conformably, the distinction between the two being chiefly of a lithological character. As nearly as the

distribution of the two series can be mapped by means of our present data, it would appear that the various bands of each set of rocks in contact with each other, correspond in their general run, and partake of the same curves and flexures." (*l. c.*, p. 106.)

Regarding Mr. Bell's observations Mr. Selwyn states: —

"It may, however, be remarked that though the facts observed undoubtedly lead to the conclusion, as stated by Mr. Bell, that the two series are in conformable sequence, yet it is far from improbable that this apparent conformity is only local, and that the result of a more extended and detailed investigation of the structure would serve to shew that there is in reality a very considerable break and much unconformity between the Laurentian gneiss and the overlying schistose and slaty strata. As regards the age of these so-called Huronian rocks, the evidence is not of the most satisfactory kind. While stratigraphically they rest directly upon highly crystalline and typical Laurentian gneisses, mineralogically they resemble as closely the chloritic, epidotic and dioritic strata of the altered Quebec group as they do those which on the shores of Lakes Huron and Superior are referred to the Huronian series." (*l. c.*, pp. 13, 14.)

In this connection it is well to remember that these rocks were referred to the Laurentian and Huronian on the same evidence that four fifths of the rocks so called are, — lithological, namely, — and that the evidence of conformability given by Mr. Bell is just as strong as any of the evidence of unconformability; also, that Logan had shown that the two formations were conformable. Moreover, it had been shown that the Huronian lay beneath the Laurentian. We do not see that Mr. Selwyn's statement has any basis of fact, it being decidedly opposed to all the evidence collected by the Canada Survey.

In the Report for 1872–73 (p. 104), Mr. Bell states: —

"The junction of the Laurentian rocks on the north with the Huronian schists of the Lake of the Woods on the south takes place on Rat Portage. The two rocks are seen almost in contact with each other, and have the same strike and dip."

Mr. George M. Dawson says of the same locality: —

"The southern end of the path passes over Huronian rocks. . . . . At the water's edge . . . . they were found to be vertical, with a strike of N. 75° E. About half-way across the Portage, and at its highest part, the rocks dip N. 17° W. $<$ 48°, and are then immediately succeeded by Laurentian gneiss, which is granitoid, and of a light pinkish-grey colour; dip N. 30° W. $<$ 89°. The junction is so close that one may actually lay the hand upon it, and the separating line is remarkably straight and even. Followed about one hundred yards westward, it was found to preserve the course of S. 67° W.,

or nearly that of the strike of both series of rocks. The gneiss at this distance has a strike of N. 72° E., and the green slate, just across the line of junction, and only a few yards removed, N. 73° E." (Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, 1875, p. 45.)

Mr. Dawson continues: —

"A mile still further eastward . . . . the Winnipeg River . . . . falls northward, across the junction of the Laurentian and Huronian series, through a narrow passage between rocky cliffs. At the fall, the rock is . . . . much hardened and of greenish colour; dip N. 10° W. < 45°. Just below the fall, the red gneiss again suddenly appears with a dip N. 18° E. 78°. . . . . Notwithstanding the close accordance of the strike of both series of rocks, and the direction of the line of junction, the evidence appears to be nearly conclusive, that the two formations are here brought together by a fault, with an extensive downthrow southward. If they are thus in contact merely by sharp folding, the relative position must be reversed, as the dips would carry the slate series below the gneiss." (*l. c.*, p. 46.)

Mr. Dawson in explaining this line of contact proceeds on the supposition that both formations are sedimentary, and hence offers the only explanation he can and preserve the Laurentian in its supposed position. Yet, so far as his descriptions go, one or both may be eruptive, which would explain the observed facts just as well. It is a pity that, with so much contact observed, he did not ascertain whether the contact was the rubbing, grinding division-plane contact of a fault; or the contact produced by one rock laid conformably, or unconformably, upon another, and both folded; or the close-welded, altering contact of an eruptive rock. Had he carefully observed the phenomena of the contact, he might have built on facts, and thus have been saved much useless speculation.

Of another locality Mr. Dawson remarks: —

"The rocks . . . . belong, as I believe, to an area of much-altered Huronian. . . . . The actual junction between the two formations at this point is concealed by water, but they show a remarkable appearance of conformity, the next rock seen, being a soft greenish slate, with a dip of S. 60° W. < 45°. [The previously given dips of the Laurentian were S. 60° W. < 50°, and S. 45° W. < 60°.] It is worthy of notice that similar apparently conformable junctions of Laurentian and so-called Huronian rocks have been noticed by Prof. Bell, as occurring on the Albany River at Martin's Falls, and also in the neighbourhood of White River." (*l. c.*, p. 29.)

Mr. Bell in the Report of Progress for 1877–78, speaking of the

junction of the Laurentian and Huronian in the Hudson's Bay district, says: —

"The junction of the two formations, which appear as usual to be conformable with each other, occurs just where the southwest area opens into the main body of the lake. Here the last of the Laurentian series consists of gray coarse rough-surfaced quartz and mica-rock. The first rock on what is considered to be the Huronian side of the boundary between the two series, consists of highly crystalline dark green hornblende schist, ribboned with fine lines of white quartz grains. It is identical in character with the hornblende schist which is usually found at the base of the Huronian bands in the region to the northwestward of Lake Superior." (*l. c.*, 21, C C.)

It is now necessary to retrace our steps, and give some attention to the Hastings or Montalban series in Canada. To these Mr. Murray called attention in the Report of Progress for 1852–53, remarking: —

"In Huntingdon, Madoc, Marmora and Belmont, many interesting diversities occur in the Laurentian series, but the rocks belonging to it become so frequently and unexpectedly covered up by projecting and outlying masses of the unconformable fossiliferous formations, in the part investigated, that it is as yet impossible to give any connected view of their arrangement." (*l. c.*, pp. 103–108.)

In the Report of 1863 the rocks were again described (pp. 32, 33), Dr. Hunt giving analyses of the limestone, as belonging to the Laurentian (pp. 592, 593).

In the Report for 1866 (pp. 91–113), the Hastings series was once more discussed by Mr. Thomas Macfarlane, who states that in the previous reports they have been shown to belong to the Laurentian. He remarks that some of the conglomerates are "lithologically not unlike some of the Huronian rocks," but does not appear to have taken ground that this series of rocks was newer than the Laurentian, as Dr. Hunt says he (Macfarlane) did (Azoic Rocks, p. 170). In the same Report Logan stated that these rocks appeared to be conformable with the Laurentian series, although they might be a higher portion of the series than had been met with elsewhere. (*l. c.*, p. 93.)

In 1867 Dr. Hunt stated that the Hastings series reposed in concordant stratification upon the Laurentian gneiss; but that the Upper Laurentian or Labradorian reposed unconformably, not only on the Lower Laurentian, but also upon the Hastings series. (*Esquisse Géologique du Canada*, pp. 5, 6). The same year Logan held that the "interruption" of a limestone zone in the Hastings series by a labradorite rock (gabbro, norite), supposed to be Upper Laurentian, showed that

this zone belonged to the Lower Laurentian. (Quart. Jour. Geol. Soc., 1867, XXIII. 253–257.)

In the same paper Mr. H. G. Vennor gives a section of the Hastings series in ascending order; this is here given, abbreviated by the omission of the descriptive portions.

1. Red felspathic strata.
2. Dark-green chlorite slates.
3. Whitish highly crystalline limestone.
4. Gray silicious or fine micaceous slates.
5. Bluish and greyish mica slates.
6. Grey and pinkish dolomite.
7. Grey micaceous limestone or calc schist.
8. Green diorite-slates.
9. Reddish granitic gneiss.

In the Report of Progress for 1866–69, Mr. Vennor again furnishes a section of the rocks of the Hastings series, referring to the one given above, quoted from the Quarterly Journal of the Geological Society, and using the words "it is here repeated." (*l. c.*, p. 144.)

The following is the section as given, in ascending order, in the Canada Report: —

Lower Division. A.

1. A great mass of highly crystalline syenitic rock.
2. Reddish and flesh coloured granitic gneiss.
3. Greyish and flesh-coloured gneiss.
4. Crystalline limestone, sometimes magnesian.

Middle Division. B.

1. Hornblendic and pyroxenic rocks.

Upper Division. C.

1. Crystalline and somewhat granular magnesian limestone.
2. Gray silicious or fine-grained mica-slates.
3. Bluish and grayish micaceous slate.
4. Gneissoid micaceous quartzites.
5. Grey micaceous limestone.

Comparison of the sections given by Mr. Vennor will show that there is hardly any resemblance between the two. No one would ever suppose, unless previously informed of the fact, that the same rocks were intended to be embraced in them. Particular notice may be called to the transference of No. 8 of the first section from near its summit to the middle of the series in the second one.

The rocks of Division B, as Mr. Vennor says, were

"seen to rest immediately upon the gneisses, Nos. 2 and 3 of Division A, but whether conformably or not is a question yet to be investigated, as in the localities where they are best represented, the massive diorites and greenstones, which form the base of this division, do not offer any clear marks of stratification."

The rocks of this division were thought to closely resemble the Huronian. Division C contained *Eozoön Canadense*, but no evidence of importance was brought forward to prove its relations to A and B. Overlying all, Trenton limestones were found.

In the Report of Progress for 1870–71, Division A was regarded by Mr. Vennor as Laurentian, and B as probably Huronian. He further states : —

"The dolomites and schists of division C lie unconformably upon the gneiss and crystalline limestones of A, while the true position of the diorites and chloritic schists of division B, appears to be at the base of C; where, however, they are not unfrequently wanting, suggesting a probable unconformity of these both with the upper and lower divisions." C is mentioned as being "seen in contact with the chloritic schists of B, without any apparent unconformity." (*l. c.*, pp. 310, 311.)

In the Report of Progress for 1871–72, Mr. Vennor remarks of Division A : —

"The age of the granite [A], on which these gold-bearing rocks [B] rest, is not yet satisfactorily determined. That it is of more ancient date than the latter, is I think clearly shown by the manner in which they repose upon its flanks, and conform to its general outline. My own conviction is, that this, and other like masses of granite, met throughout the Hastings district, represent eruptions which probably took place towards the close of the Laurentian period, or at some time prior to the deposition of the greenstones, schists, dolomites and limestones of Divisions B. and C." (*l. c.*, p. 130.)

In the Report for 1872–73, Mr. Vennor remarks : —

"The red granites [A] also occur in many localities throughout the area just described, but in a very irregular manner, so as to render it difficult to determine their age in relation to the other rocks. . . . . In the vicinity of the East and West Mountains in Grimsthorpe, they are unstratified, and often appear to be of more recent date than the white mica granites, and even than the diorites of division B." (*l. c.*, p. 140.)

In the Report of Progress for 1874–75, Mr. Vennor groups the rocks of Lanark County as follows : —

I. Mica Schist Group.
II. Dolomite and Slate Group.

III. Diorite and Hornblende Schist Group.
IV. Crystalline Limestone and Hornblende Rock Group.
V. Gneiss and Crystalline Limestone Group.
VI. "Embracing coarse orthoclase gneisses, felsites, garnetiferous gneisses, pyroxenites, crystalline limestones and white quartzo-orthoclase rock."

From its lithological characters he thought it probable that the mica schist group (I.) should be placed near the summit of Division B, and beneath the gray calc-schists and impure limestones of Division C of the Hastings series. He also states that the belt of red gneiss (Division A, Hastings series)

"separates the mica-schist group (I.) from the dolomite and slate group (II.). It appears to overlie the former, and invariably shows the same constant dip to the south-east and east. But extended observations on its course for a number of miles seem rather to show that its present position is due to an uplift or overturned elevation of an older gneiss series. . . . . The rock is a fine-grained granitic gneiss, composed largely of flesh-coloured feldspar and greyish quartz, and differing in no respect from most of the gneisses heretofore described as Lower Laurentian."

Group V. was found apparently overlying Group IV., the limestone group. It would seem that *Eozoön* had been found in Groups III. and IV. (*l. c.*, pp. 105–165.)

Mr. Selwyn, the next year, in quoting from Mr. Vennor's work, writes : —

"The geological structure of this section of the country is exceedingly intricate, but when worked out will be both important and instructive. It is now apparent that the rock groups referred to in my last report as I. II. III. and IV., constitute together the lower members of one great crystalline series, while V. and VI., of the same report, constitute its upper members. These groups include the so-called Hastings series of the earlier reports, and the Eozoon has now been found from the lowest to the highest group. . . . . Throughout this region the lowest rock is a massive red, orthoclase gneiss, in which, as a rule, no bedding planes can be recognized, and the groups above enumerated overlie it in, probably unconformable sequence. In many places, in connection with the Bonnechere limestone trough, labradorite rocks were observed, but these appear to be quite conformable with the rest of the series." (Report of Progress, 1875–76, p. 4.)

In the Report of Progress for 1876–77, Mr. Vennor remarks : —

"Now these rocks represent Division B, and a part of C, of the *Hastings series* which have been compared, by some investigators, to the Huronian, but

which I have now shown are really only the westward extension of the diorites hornblende schists and mica-slates of Lanark and Renfrew counties, or, in other words, of Groups I., II. and III. But these last, as we have also shown, are simply a low portion of the gneiss and limestone series which has always been looked upon as typical Laurentian. Consequently, we are finally led to the important conclusion that the *Hastings series* is not, as it has up to the present been considered, the most recent, but rather the oldest portion of the great system of rocks we have been investigating from the year 1866 to 1875 inclusive. Further, it was clear that this great crystalline, gneiss and limestone series rested upon a still older gneiss series, in which no crystalline limestones had yet been discovered. This series is referred to as Division A in the Report of Progress, 1866–69, where, however, limestones are, incorrectly, mentioned as occurring in it. It . . . . is the rock which may be said to form the back-bone of Eastern Ontario, and the nucleous around which have been deposited all succeeding formations. This, then, is undoubtedly Archæan and Lower Laurentian, and consequently the crystalline limestones and gneisses constitute a series which would come in beneath Sir W. E. Logan's Upper Laurentian or Labradorite series. As regards the existence of this latter as a distinct formation, however, I entertain grave doubts." (*l. c.*, p. 254.)

As a reason for these doubts he points to several localities where he says the labradorite (Norian) rock is interstratified with the limestones of this series, and to others where it is conformable with the Hastings series. Mr. Vennor concludes : —

"So far, then, my investigations in Eastern Ontario show but three great divisions or groups of rocks, namely : —

"1. A great gneissic and syenitic series, without limestones.

"2. A thinner gneissic series with labradorites and limestones.

"3. Lower Silurian (Potsdam to Trenton)." (*l. c.*, p. 277.)

In 1877 Mr. Vennor said (Am. Jour. Sci., 1877, (3) XIV. 313–316) : —

"We find that there still exists a great *Azoic* formation, consisting of syenite and gneiss (?) without crystalline limestones. In this there are but little indications of stratification. Occasionally a limited surface presents an approach to an *obscure stratification*, but this does not appear to be due to the deposition of sediment. This rock forms the back-bone of Canada. On it there has been deposited a great series of gneisses, schists, slates, crystalline limestones and dolomites, which, although heretofore grouped with the former, is clearly distinct and unconformable. . . . . *Eozoon Canadense* belongs undoubtedly in the main to the highest band of crystalline limestone yet found. . . . . I may simply state that I consider both the Huronian and Upper Laurentian of Sir W. E. Logan to belong rightly to my second division, which I must for the present call Upper Laurentian. . . . . I have found Labradorite rocks clearly interstratified with several of my bands of limestone, and I fail entirely to dis-

cover Sir William's upper distinct system — yet I have been over the same ground. The *Huronian* and *Hastings series of rocks* I believe to be simply an altered condition, on their westward extension, of the lower portion of my *second system*."

Retracing our steps, we see that in 1870, under date of December 13, 1869, Dr. Hunt held that the *Eozoön Canadense* of Madoc, and hence the Hastings series, occurred in the Laurentian. (Am. Jour. Sci., 1870, (2) XLIX. 75–78.) Later, under date of May 10, 1870, he referred the Hastings series to the Terranovan, but it would seem that, when the term Terranovan series was first employed by him, it was regarded as being, in part at least, Potsdam. He remarks: —

"From these investigations of Mr. Murray we learn that between the Laurentian and the Quebec group, there exists a series of several thousand feet of strata, including soft bluish-grey mica-slates and micaceous limestones, belonging to the Potsdam group; besides a great mass of whitish granitoid mica-slates, whose relation to the Potsdam is still uncertain. To the whole of these we may perhaps give the provisional name of the Terranovan series, in allusion to the name Newfoundland." (Am. Jour. Sci., 1870, (2) L. 85, 87, 88.)

To this series he referred the White Mountain rocks, as well as certain rocks in New Brunswick.

In the Twenty-first Annual Report of the Regents of the University of New York, Dr. Hunt remarked of the Hastings series (1871, p. 48): —

"In the county of Hastings, in the province of Ontario, not less than 21,000 feet of strata, consisting of crystalline schists, limestones and diorites, are found resting conformably upon the Laurentian series."

In a postscript (*l. c.*, p. 98) he states: —

"More recent researches by the Geological Survey of Canada have shown that the rocks of Hastings county . . . . rest unconformably upon the Laurentian, and belong to one and possibly two distinct systems. The upper and larger portion consists in a great part of mica-schists and micaceous limestones, while at the base are great masses of dioritic and hornblendic schists with iron ore, possibly of Huronian age."

In some remarks of Dr. Hunt, in 1873, it was stated: —

"As regards the Norian, which had once been joined by the Laurentian, Dr. Hunt had elsewhere shown that we had reason for suspecting that it might be more recent than the Huronian, and possibly than the Montalban, a conclusion which appeared to be confirmed by the facts made known by Hitchcock." (Proc. Bost. Soc. Nat. Hist., 1873, XV. 310.)

In 1875 Dr. Hunt remarked of the White Mountain or Montalban series (Hastings series) : —

"These ancient rocks are also largely represented in Hastings County, Ont., where they occupy a position between the Laurentian and the fossiliferous limestones of the Trenton group, and are the equivalents of similar limestones and micaceous quartzites in Berkshire County, Mass., and elsewhere in New England." (Proc. Bost. Nat. Hist., 1875, XVII. 509.)

In 1878 Dr. Hunt referred the limestones of the Hastings series to the Lower Taconic (Taconian). (Proc. Bost. Soc. Nat. Hist., 1878, XIX. 278 ; Preface to Second Edition of Chemical Essays, pp. xxii, xxvi.) In the last quoted work the Hastings limestones and slates are said to lie between the Huronian and Trenton. In 1879 the Norian was said by Dr. Hunt to rest unconformably upon the gneisses and crystalline limestones of the Laurentian, and held to be older than the Huronian. The Huronian was also said to rest unconformably on the Laurentian, on the north shores of Lakes Huron and Superior, thus rejecting the positive evidence given by Messrs. Logan and Bell of their conformable relations (in one case underlying however) on the north side of Lake Superior.

The rocks of the Montalban series "are believed to be younger than the Huronian, although some geologists have supposed them to be older." (The Geologist's Travelling Hand-Book, pp. 10–13.) The Taconian in the previous year was said to be found reposing alike on the Laurentian, Huronian, and Montalban, and to be overlain, in apparent unconformity, by the Upper Taconic, which was considered to be identical with the Quebec group of Logan. (Nature, 1878, pp. xviii, 444.)

In the Report of Progress for 1877–78, Mr. Selwyn made some remarks on the Quebec Group and the older Crystalline Rocks of Canada." (A., pp. 1–15.)

He separated the Quebec into three groups : —

1. The Lower Silurian group.
2. The Volcanic group, probably Lower Cambrian.
3. The Crystalline Schist group. (Huronian ?)

Mr. Selwyn further said : —

"In any case, I think, there are very few who would agree with Dr. Hunt in the general proposition that the diorites and serpentines of the Quebec group are of sedimentary origin, and the amygdaloids altered argillites ; unless all contemporaneously interbedded volcanic products are to be considered as of sedimentary origin, the Quebec group might be said to present some of the most

marvellous instances on record of '*selective metamorphism*.' But whether this is so or not, there seem to be no good grounds for assigning either an age or an origin to the cupriferous diorites, dolerites, and amygdaloids of the Eastern Townships different from that of the almost identical rocks of Lake Superior."

Of the Hastings series he says: —

"The gradual progress of the work, however, from west to east has now, I think, conclusively demonstrated that the Hastings group, together with the somewhat more crystalline limestone and gneiss groups, ... form one great conformable series, and that this series rests quite unconformably on a massive granitoid gneiss."

Of the Norian rocks he said: —

"In not one of the several areas where they are known to occur in Canada, have they yet been mapped in detail, and even their limits, as indicated on the geological map, are more or less conjectural. . . . . Professor Hitchcock shews that they rest unconformably on the upturned edges of the '*Montalban*' gneisses, leading to the conclusion that the gneisses of the White Mountains are older than the 'Norian,' whereas Dr. Hunt, solely, I believe, on mineralogical considerations, supposes these same '*Montalban*' gneisses to constitute a system newer than the Huronian. Here, then, as in the Hastings region, we find theory and experience at variance. . . . . If it is admitted — which, in view of the usual associations of Labrador feldspars, is the most probable supposition — that these anorthosite rocks represent the volcanic and intrusive rocks of the Laurentian period, then also their often massive and irregular, and sometimes bedded character, and their occasionally interrupting and cutting off some of the limestone bands, as described by Sir W. E. Logan, is readily understood by one who has studied the stratigraphical relations of contemporaneous volcanic and sedimentary strata, of palæozoic, mesozoic, tertiary and recent periods. Chemical and microscopical investigation both seem to point very closely to this as the true explanation of their origin. That they are eruptive rocks is held by nearly all geologists who have carefully studied their stratigraphical relations. . . . . When we recall the names of Dahl, Kerulf and Torrell in Norway, Maculloch and Geike in Scotland, Emmons, Kerr, Hitchcock, Arnold Hague, and others in America, all of whom consider these norites as of eruptive origin, we may well pause before accepting Dr. Hunt's conclusions respecting them, and that they should often appear as 'bedded metamorphic rocks,' . . . . is quite as probable as that we should find the mineralogically similar dolerites occuring in dykes and bosses, and in vast beds interstratified with ordinary sedimentary deposits of clay, sand, etc., as we do over wide areas in Australia and elsewhere. In conclusion, I may say that I fail to see that any useful purpose is accomplished, in the present stage of our knowledge of the stratigraphical relations of the great groups of rocks which underlie the lowest known Silurian or Cambrian formations, by the introduction of a number of new names such as those proposed by Dr.

Hunt for systems which are entirely theoretical, in which category we may in my opinion include the Norian, Montalban, Taconian and Keeweenian. These, one and all, so far as known, are simply groups of strata which occupy the same geological interval, and present no greater differences in their physical and mineralogical characters than are commonly observed to occur both in formations of the same epoch in widely separated regions, and when physical accidents, such as contemporaneous volcanic action or subsequent metamorphism have locally affected the general character and aspect of the formation within limited areas. . . . . Unfortunately in Canadian geology, hitherto, stratigraphy has been made subordinate to mineralogy and palæontology, and, as the result, we find groups of strata which the labours of the field geologists during the past ten years have now shewn all to occupy a place between Laurentian and Cambrian, assigned to Carboniferous and Upper Silurian in New Brunswick and Nova Scotia, to the peculiar palæontological Lévis group and its subdivision, Lauzon and Sillery, in the Eastern Townships, and to Lower and Upper Laurentian, Huronian, Lower Silurian and Triassic on the north side of the St. Lawrence valley and around Lake Superior. The same system of mineralogical stratigraphy is now further complicating and confusing the already quite sufficiently intricate problem by the introduction of the new nomenclature I have referred to, and in some cases these names are applied regardless of and in direct opposition to well ascertained stratigraphical facts. A similar unfortunate instance of palæontological stratigraphy is found in the history of the Quebec group ; and especially in the late introduction in it of the belt of supposed Potsdam rocks, about which I have already stated my opinion. In the reconstruction of the geological map of Eastern Canada, — and in this I include the country from Lake Winnipeg to Cape Breton and Labrador, — rendered necessary by the present state of our knowledge, I should propose to adopt the following divisions of systems to include the groups enumerated : —

"I. LAURENTIAN :

"To be confined to all those clearly lower unconformable granitoid or syenitic gneisses in which we never find interstratified bands of calcareous, argillaceous, arenaceous and conglomeratic rocks.

"II. HURONIAN :

"To include — 1. The typical or original Huronian of Lake Superior and the conformably — or unconformably, as the case may be — overlying upper copper bearing rocks.

"2. The Hastings, Templeton, Buckingham, Grenville and Randon crystalline limestone series.

"3. The supposed Upper Laurentian or Norian.

"4. The altered Quebec group, as shewn on the map now exhibited, and certain areas not yet defined between Lake Matapedia and Cape Magnereau in Gaspé.

"The Cape Breton, Nova Scotia and New Brunswick pre-Primordial subcrystalline and gneissoid groups.

"III. Cambrian:

"In many of the areas, especially the western ones, the base of this is well-defined by unconformity, but in the Eastern Townships and in some parts of Nova Scotia it has yet to be determined. The limit between it and Lower Silurian is debatable ground, upon which we need not enter. . . . . One point I wish particularly to insist on is, that great local unconformities and lithological differences may exist without indicating any important difference in age, especially in regions of mixed volcanic and sedimentary strata, and that the fact of crystalline rocks (greenstones, diorites, dolerites, felsites, norites, &c.,) appearing as stratified masses and passing into schistose rocks, is no proof of their not being of eruptive or volcanic origin — their present metamorphic or altered character is, as the name implies, a secondary phase of their existence, and is unconnected with their origin or original formation at the surface, but is due partly to original differences of composition and partly to the varying physical accidents to which they have, since their formation, respectively been subjected." (*l. c.*, pp. 1–15 A.)

Mr. Selwyn's views were discussed, and in part objected to, by Mr. Thomas Macfarlane. (Canadian Naturalist, 1879, (2) IX. 91–103.)

Dr. Hunt very ingeniously derives comfort from the preceding paper by ignoring most of it and claiming: —

"The pre-Cambrian age of these crystalline schists in Eastern Canada has now been clearly proved by the . . . . recent stratigraphical studies of Selwyn, as announced by him in 1878." (Proc. Am. Assoc. Adv. Sci., 1879, XXVIII. 286.)

In 1879 Dr. Dawson remarked that

"the idea that the Middle Laurentian, the horizon of Eozoon Canadense and of the great Phosphate and Graphite deposits, is identical with the Hastings group, or with the Huronian, has, I am fully convinced, after some study of the Lake Huron, Madoc and St. John exposures of these formations, no foundation in fact." (Canadian Nat., 1879, (2) IX. 180.)

Dr. Dawson, however, gave no proof of this statement, while Mr. Vennor had worked out the subject according to the stratigraphical methods of the Canadian Survey, — a labor of ten years; this is better than an unsupported assertion.

NEW BRUNSWICK.

In this Province it is not necessary to go back in the geological history earlier than the first edition of Principal J. W. Dawson's Acadian Geology, for in his writings and those of Messrs. Bailey and Matthew nearly all the evidence bearing on our subject is to be found. The methods of work appear to be the same as those of the Canadian Survey, and therefore similar results were to be expected.

In 1855 Dr. J. W. Dawson, on lithological grounds, would have referred the rocks in the vicinity of St. John to the Lower Carboniferous; but on account of the statement of Dr. Gesner, that similar rocks underlie the Carboniferous sandstones, he says, "I must be content in the mean time to consider them as silurian rocks of uncertain age." (Acadian Geology, 1st ed., p. 324.)

Later he states regarding these rocks: —

"The limestone and its associated shales underlie unconformably the Lower Carboniferous conglomerate. . . . . This arrangement is general throughout the belt to which the St. John rocks belong. The whole of the beds of the St. John group, appear to be conformable to one another, and to constitute one formation." (Canadian Nat. and Geol., 1861, (1) VI. 164.)

From the resemblance of these rocks to the Devonian of Gaspé, and from the plants found in them, he considers them all to be of that age.

Later he writes regarding this entire series of rocks: —

"The Devonian age of the upper members of this great series of beds I regard as established by their fossils, taken in connexion with the unconformable superposition of the Lower Carboniferous conglomerate. The age of the lower members is less certain. They may either represent the Middle and Lower Devonian, or may be in part of Silurian age." (Quart. Jour. Geol. Soc., 1862, XVIII. 303.)

In the later editions of this Acadian Geology (1868, 1878), he follows in the main Messrs. Bailey and Matthew; therefore we need only incidentally refer to those editions.

Mr. Geo. F. Matthew, in 1863 (Canadian Naturalist, 1863, (1) VIII. 241–260), divided the rocks at St. John into the following groups: —

"1st Portland Series containing fragments of plants in the upper beds; 2d, Coldbrook Group; 3d, St. John Group, containing lingula, a conchifer,

annelides, and coprolites ; 4th, Bloomsbury Group ; 5th, Little River Group, containing numerous plants, several crustaceans, and wings of insects, etc. ; 6th, Mispeck Group." (*l. c.*, pp. 244, 245.)

He states that no proof has been observed that the St. John group is unconformable with either the overlying or underlying rocks. (*l. c.*, p. 247.) The Mispeck group is said to contain fragments like the lower slates of the Coldbrook group. (*l. c.*, p. 253.) The rocks in the vicinity of Black River, to which the name Coastal group was afterwards given, were here classed under the Little River group. This group was divided into two parts, the lower called the Dadoxylon sandstone, and the upper the Cordaite shales. He says it seems clear that the Black River rocks mentioned above

"form a part of the Upper Devonian series, because, — 1st They overlie the Dadoxylon sandstone conformably (or nearly so). 2nd They underlie carboniferous deposits unconformably. 3rd They partake of the flexures of the Devonian series, which preceeded the formation of the Lower Carboniferous conglomerate. . . . . I have connected them with the cordaite shales, but it is quite possible that the upper part may be altered beds of the Mispeck group." (*l. c.*, pp. 252, 253, 256–258.)

Mr. Matthew's statements regarding the age of the entire series are far from being clear. In some places he appears to regard them as Devonian, in others as being in part Devonian and in part Silurian. His language admits of no other interpretation than that he regarded the Coldbrook group as being of Devonian age. (*l. c.*, pp. 258, 259.)

In 1865 the same geologist referred the Portland series to the Laurentian and the Coldbrook group to the Huronian. The Coldbrook rocks were placed in two divisions, a lower and an upper. The upper division is said to be "largely composed of erupted materials, diorites, tufas, and volcanic mud," the same as the Huronian of Canada, and to be "*conformably* surmounted by the lowermost strata of the Lower Silurian formation."

He further remarks : —

"Considering, therefore, the origin of these deposits as well as their position relative to the more ancient series and the Lower Silurian beds above, we have little hesitation, notwithstanding that the latter are conformable to them, in assigning these semivolcanic sediments to the 'Huronian series' of Logan."

The St. John group was regarded by him as being the equivalent of the Potsdam, Calciferous, and possibly Chazy formations.

A series of rocks which cover an area of about seventy miles long and

twenty wide, stretching northeastwardly from Passamaquoddy Bay, and including the highest eminences in the southern counties, was assigned to the Upper Silurian. The Bloomsbury, Little River, and Mispeck groups were placed in the Middle and Upper Devonian, and were said to rest unconformably upon the Laurentian, Huronian, Lower Silurian, and Upper Silurian strata, and it was stated that the Primordial shales appear to overlie the Huronian without any appreciable discordance between the two. (Quart. Jour. Geol. Soc., 1865, XXI. 422–434.)

In Messrs. Bailey, Matthew, and Hartt's "Observations on the Geology of Southern New Brunswick," 1865, a work prepared for the press by Prof. Bailey, the rocks referred to the Huronian and Laurentian ages are so placed on theoretical and lithological grounds. Regarding the age of the Portland group, here assigned to the Laurentian, he writes: —

"It might readily be supposed that the extreme metamorphism exhibited by the rocks of the Portland Group would be accepted as conclusive evidence of their great antiquity. Indeed the fact of such antiquity could scarcely have been doubted, were it not for the intimate association and almost entire conformability between the beds of this and the overlying groups, which have heretofore induced all the observers who have examined the district to link them in a single series. As the latter are unquestionably of Upper Devonian age, the beds of Portland were supposed to represent either a portion of the Lower division of the same formation, or possibly the upper part of the Silurian." (*l. c.*, p. 18.)

The reasons for assigning it to the Laurentian are, in brief, partly lithological, and partly because it seemed to them probable that the Coldbrook group was Huronian, and therefore the syenites (Portland group) must be Laurentian. (*l. c.*, p. 18.) Between the Coldbrook group and the underlying syenite and limestone, Prof. Bailey states that Mr. Matthew observed "evidence of slight unconformability." (*l. c.*, p. 49.) Again he remarks: —

"During the deposition of the various rocks referred to the Azoic and Silurian Ages, a prolonged period of repose prevailed throughout the districts where these rocks occur, broken only by the volcanic activity which marked the epoch of the Coldbrook Group. . . . . Through all these vast intervals of time no evidence exists to show that any violent disturbances broke the general quiet, unless it be the folding of the Portland and Kingston rocks, and even this may have been the result of a later date. Each formation was quietly deposited upon that which preceded it, the almost entire conformability which now marks their succession being conclusive evidence that no period of marked upheaval prevailed between the deposits of one epoch and those of another." (*l. c.*, p. 50.)

Of the Bloomsbury group, which later was united to the Coldbrook group, he states : —

"The association of the Bloomsbury rocks with the Groups which are to follow, is conclusively proved by the general similarity of their deposits, by their entire conformability, and the *absence* of such perfect conformability between these and the Primordial (or Saint John) rocks below. As the overlying beds have been shown to be unquestionably of Upper Devonian age, there can be no hesitation in referring the Bloomsbury Group to the same horizon." (*l. c.*, p. 53.)

The Coldbrook group, while nominally underlying the St. John group, was found in another place overlying it. In this locality it seems that the rocks were recognized as Coldbrook (Huronian) from lithological characters, and their stratigraphical position explained by a reversed folding. (*l. c.*, pp. 23, 28, 29.)

In regard to the age of the Kingston group, which with the Mica Schist formation appears to be the Upper Silurian of Matthew, it is said : —

"We have only the general lithological characters and the stratigraphical relations upon which to rely for the determination of this important question. As the conclusions derived from these two independent sources accord exactly, we may consider the position of this formation as established with some degree of certainty." (*l. c.*, p. 38.)

Again he states, quoting from Mr. Matthew : —

"Their relations to other groups, as well as their appearance when altered, indicate that the Kingston rocks and their associates may be provisionally looked upon as Upper Silurian, though Middle Silurian and Lower Devonian beds may also occur. The only objection to this view is the absence of such hard rocks along the outcrops of the soft Lower Silurian strata in Saint John County, where these latter are covered by deposits of Upper Devonian age. This may be accounted for by denudation subsequent to their deposition, or by supposing an elevation of the older rocks above the sea when those of Kingston were being formed." (*l. c.*, p. 39.)

The arrangement of the formations in this report, it has been seen from the above, is as follows : —

LAURENTIAN. The Portland group, if it is not Huronian, doubt existing.
HURONIAN. Coldbrook group, probably.
POTSDAM AND QUEBEC. St. John group.
UPPER SILURIAN. { The Kingston group.
{ Limestones of Dalhousie.

Lower Devonian.	Possibly some portion of the Kingston group.
Upper Devonian.	Mispeck group.
	Little River group.
	Bloomsbury group.

In a paper presented to the American Association for the Advancement of Science (1869, XVIII. 179–195) by Messrs. Bailey and Matthew, it is remarked that "several hills of crystalline felspar rock, associated with hypersthene," were, on the authority of Dr. Hunt, referred to the Labrador or Upper Laurentian series. (*l. c.*, p. 181.) The Kingston series the authors were inclined to regard as Upper Silurian and Devonian. The overlying formations below the Carboniferous, excepting in their subdivisions, and being classed as Siluro-Devonian, remained about as in 1865. This paper was revised up to April, 1870.

In a joint report by Messrs. L. W. Bailey and G. F. Matthew (Geology of Canada, Report of Progress, 1870–71, pp. 13–240) numerous changes were made in the supposed sequence of the formations, Dr. Hunt having worked in the field with them. Lithological evidence had been thought sufficient authority for enlarging the amount of Laurentian rocks; and the finding of a few pebbles in some of the granitoid masses was regarded as proof that they were altered conglomerates.

The rocks referred, on lithological evidence, to the Huronian, were divided into three groups: the Coldbrook, Coastal, and Kingston. The former was found in some places to overlie the Primordial or St. John group, and to conformably underlie rocks of Devonian age, to which age these rocks (the Bloomsbury group) had formerly been referred. However, lithological characters being then regarded as more weighty than stratigraphical ones, this difficulty, together with some others, was surmounted in the following manner.

"Prior to the work of the present survey, the river St. John, at the Suspension bridge, was considered as marking the extreme western limit of the Huronian rocks of St. John County, the only sediments noticed to the westward of this point, which bore much resemblance to them, being supposed, on stratigraphical grounds, to be more recent. . . . . Recent observations, however, have led us to the conclusion that a part of these supposed more recent sediments are in reality the Huronian strata brought up by a fold, and by an overturn of the whole series made to rest upon newer strata. . . . . The diorites and schists of Bloomsbury Mountain, although apparently resting upon the slates of the St. John group, and overlaid by Devonian sandstones, which conform to them in dip and strike, are now also regarded as Huronian strata. . . . . On both sides of Musquash Harbor a series of hard green epidotic subcrystalline schists, sometimes with dark green serpentine, may be seen resting

upon black carbonaceous crumbling shales. . . . . These latter dark colored rocks resemble very closely some portions of the St. John group as seen in the city of St. John, and are supposed to be continuous with them through a belt of similar rocks, extending across the peninsula of Pisarinco, and coming out at Mill Creek in Pisarinco Harbor. In this view, it is probable that the structure indicated in this group at St. John, and to be presently noticed, will hold good here also, viz.: That the St. John group is inverted upon itself, and that the green crystalline schists, though overlying that group, are in reality more ancient and probably of Huronian age." (*l. c.*, p. 60.)

Of the Huronian rocks at Ratcliffe's mill-stream it is stated that

"they overlie the Primordial strata, both formations occupying a nearly vertical position, with a slight southward inclination, and both being inverted." (*l. c.*, p. 63.)

Of the Bloomsbury group it is again remarked: —

"In our earlier publication, this hill . . . . has been referred, from the fact of its overlying the slates of the St. John group, to the Devonian series; but the close resemblance in aspect borne by the rocks composing it to those so largely developed to the north and north east, from which they are separated only by a narrow valley, renders it more probable that the great mass of strata in this hill is of Huronian age, and that, though here apparently resting upon the Primordial strata (which in the valley alluded to dip southerly under Bloomsbury Mountain) they are in reality more ancient than these latter, and are here brought up along a line of fault in a similar manner to those of Ratcliffe's millstream." (*l. c.*, pp. 63, 64.)

The upper part of the Coldbrook group, from its conformably underlying at other places the St. John group, and from its containing pebbles supposed to have been derived from the lower portion of the Coldbrook group, was regarded as forming the base of the Primordial or St. John group, (*l. c.*, p. 59,) an unfossiliferous portion of the latter. As we have seen before, part of the Coldbrook group was found resting on the St. John group; the latter was supposed to have been inverted upon itself, which would explain the fact that Huronian rocks were overlying Primordial ones. (*l. c.*, pp. 136–139.)

Of the rocks of the Coastal group it is said that they

"have been found to overlie, at several points, strata of Upper Silurian and Lower Devonian age. Hence, those occurring along the coast were, in our report on the geology of Southern New Brunswick, described in connection with the Devonian rocks of St. John County, under the denomination of the Coastal group, Dr. Hunt, however, who has examined a large number of specimens collected from these rocks, and has visited a part of the districts in which they occur, is of opinion that their lithological aspect is such as to indicate much

greater antiquity. In the presence of diorites, felsites and other crystalline rocks, he finds this series to resemble the Huronian strata of St. John County. Portions of it do indeed correspond in the appearance of the beds to the Huronian of that county, but the series of the coast is much more voluminous than the resembling parts of the Coldbrook group, and contains conglomerates, limestones, micaceous slates, feldspathic grits, etc., which have not been recognized among the Huronian rocks of St. John County, first described as the Coldbrook group." (*l. c.*, p. 83.)

In this connection it may be well to remember that later Dr. Hunt acknowledged that at that time his "opportunities for studying the Huronian had been very imperfect."

Again Messrs. Bailey and Matthew say: —

"These Devonian sediments appear to dip beneath those of the Coastal type at those points where the two have been observed together, but, as the latter are lithologically unlike those of the Devonian series, and do strongly resemble those elsewhere referred to the Coastal group, we suppose that the appearance alluded to is due to a dislocation." (*l. c.*, p. 94.)

Again, of the Coastal rocks in another locality: —

"Their superposition on the Dadoxylon sandstone, however, being probably the result of a fault and overlap, they are considered as pertaining to the same horizon with the strata already described along the coast westward of St. John, and in Charlotte County, to which the designation of the Coastal group has been given." (*l. c.*, p. 98.)

It is also stated that, although Upper Silurian strata were found "intercalated with the Kingston rocks, the intimate association of the two is evidently accidental"; hence the Kingston rocks are Huronian, especially as the Coastal group overlies them. How the "accidental intercalation" could occur between Huronian and Upper Silurian rocks is not explained.

We thus see that, while the Portland group remains in the Laurentian, the Bloomsbury group, formerly regarded as Upper Devonian, is placed in the Lower Coldbrook group; the Coldbrook group divided into two portions, and the upper one assigned to the St. John group; the Kingston group taken from the Upper Silurian and Lower Devonian, and placed above the Lower Coldbrook in the Huronian; and the Coastal group formed from part of the Little River group of the Upper Devonian and placed in the Huronian above the Kingston group.

In this way two groups of rocks are intercalated between the two members of the Coldbrook group. It is necessary to remember, while

observing this extraordinary rearrangement of the rocks in Southern New Brunswick, throwing them from 8,000 to 15,000 feet perpendicular, that it has been stated all along that the Azoic and Silurian ages were ages of stability and repose, excepting some volcanic action, and that the formations were conformable to one another, with the possible exception of a slight unconformability between the Portland and Coldbrook groups. It would seem, then, that lithological resemblances — especially if accompanied by the dictum of Dr. Hunt — were regarded as being more important than stratigraphical facts. There does not appear to be any evidence of faults or overturns; but these were imagined in order to explain the resemblance in lithological characters, and carry out the views of the Canadian geologists. The language of Messrs. Bailey and Matthew admits of no other possible construction.

The natural explanation of the lithological resemblances seems to us to be, that similar eruptive materials were originated in different ages. Such faults and overturns should by no means have been introduced, unless some evidence could be brought forward of their actual existence.

In the Report of Progress for 1876–77, Mr. Matthew regards the Coastal group as Laurentian, and the Kingston group as partly Upper and partly Lower Silurian. At one place this group is said to unconformably overlie the St. John group, and to contain pebbles probably derived from it. (*l. c.*, pp. 334-350.)

In the Report of Progress for 1876–78, the Kingston series is regarded by the same gentleman as Upper Silurian on account of palæontological evidence, although lithologically it appears to be Huronian, and to dip beneath that group. (*l. c.*, p. 6 E.)

In Prof. Bailey's report, in the same volume, the Coldbrook and Coastal groups remain in the Huronian, and the Upper Coldbrook series is taken away from the St. John group, and replaced in the Huronian below the Coastal, on account of the unconformability of certain rocks supposed to belong to the series. (*l. c.*, pp. 28, 29 DD.)

The Huronian is conformably interbanded with the Devonian rocks at Bloomsbury Mountain and westward from Black River; but that this does not prove that they belong to the same series is said to be shown by the conglomerates of the Devonian being largely made up of *débris* from the Huronian, and by the absence of conformability in some places. It would seem that in much of the district in question Prof. Bailey has no other than lithological evidence to prove that he is dealing with Devonian strata. (*l. c.*, pp. 21–23 DD.) The statement that the De-

vonian conglomerates contain pebbles from the Huronian could only be accepted after a careful examination of the rocks in question by a competent lithologist.

Mr. R. W. Ells, in the same volume, describes some Huronian and Laurentian rocks, claiming that they are unconformable, and that "in many places a gradual transition can be traced from the green slates through schists, felsites and gneisses to the syenites." (*l. c.*, p. 4 DD.) No evidence is advanced to prove either statement; and in regard to the latter one it is to be wished that some of the places where these phenomena can be seen might be pointed out, so that the actual existence of such a transition might be demonstrated. The rocks described by Mr. Ells as Laurentian and Huronian were in 1865 assigned to the Devonian, but in 1871, under the divisions of Coldbrook, Coastal, and Kingston, were included in the Huronian by Messrs. Bailey and Matthew.

In the Report on the Geology of Canada for 1878–79 is a contribution by Messrs. Bailey, Matthew, and Ells. In this the Laurentian or Portland rocks are divided into two groups, one of which is regarded as being more recent than the other, but no proof of this is given. The Coldbrook, Coastal, and Kingston groups were placed in the Huronian. No instance was observed of the Coldbrook resting upon the Laurentian; but as the Coastal lies upon the Coldbrook and the Laurentian, there was thought to be no reasonable doubt as to the true succession. The Coastal was also said to contain fragments of the Coldbrook in it. The Kingston was replaced in the Huronian, because beds containing Upper Silurian fossils were found to abut against those rocks, instead of forming a continuous series. The St. John group was placed in the Cambrian, while in the Cambro-Silurian were included rocks which in 1871 were described as Laurentian, etc.

In a paper read before the American Association for the Advancement of Science, August, 1880, Prof. Bailey remarked: —

"Beginning with the older formations, we have found no reason to depart from the view first advanced by us, that, beneath the fossiliferous rocks of the St. John or Acadian Group, there exist two, if not three distinct formations, equivalent in part, at least, to the so-called Laurentian and Huronian formations in other parts of Canada. It has been objected that this reference has been based upon the wholly valueless ground of lithological characteristics, and that the strata in question, being destitute of fossils, may even be Silurian; but such objection entirely ignores the fact that, accompanying such differences of lithological character, there is, at the same time, the most marked evidence of unconformability. A study of the Primordial rocks east of St. John, in

1879, placed this point beyond question, they having been then found by me to occupy irregular troughs in the older Pre-Silurian rocks, resting sometimes upon one and sometimes upon another of the subdivisions of the latter, crossing their strike obliquely, and having at their base coarse conglomerates made up of the waste of the underlying formations. The latter being thus unquestionably of Pre-Silurian age, it is equally obvious that in their vast thickness, in the markedly different conditions under which their several divisions were accumulated, and finally in the further unconformability indicated between these divisions, they represent a vast interval of time, and are at least as old as the Huronian and portions of the Laurentian system, which in all their physical characters they so nearly resemble. No more marked coördination of distant formations could be desired than is here furnished between the great mass of coarse gneisses at the base of the series, associated with finer gneisses, quartzites, graphitic and serpentinous limestones and dolomites (the probable equivalents of the Hastings' series of Mr. Vennor), and capped by the great volcanic series of the Huronian, with its petrosilicious and felsitic strata, ash-rocks and agglomerates, the whole unconformably traversed by bands of the lowest Cambro-Silurian, and the similar succession observed about Lake Huron and elsewhere. . . . . It should be added in this connection that in the rocks here assigned to the Huronian, there are as a whole two well-marked divisions, the lower (or Coldbrook group) consisting almost entirely of fine grained felsitic strata, with diorites, amygdaloids and porphyries, and the upper (or Coastal group) of schistose rocks, often talcoid or nacreous, with conglomerates and limestones and holding ores of copper, and that between the two there is not unfrequently evidence of at least a partial unconformability, but in general the relations to each other are much more intimate than are their relations either to the underlying Laurentian, or to the Primordial strata which overlie them." (*l. c.*, pp. 416, 417.)

In this paper the Kingston was separated by Prof. Bailey into two groups : one of these was placed in the Huronian, and the other in the Lower Silurian. This author further states, that the Upper Silurian

"age can now be definitely assigned to the very remarkable group of rocks surrounding Passamaquoddy Bay, and which include the peculiar orthophyres or felspar-porphyries of Eastport and Pembroke, Me., these latter having been found to rest directly and almost horizontally upon a series of fossiliferous sandstones, identical with those which at the last-named locality have been long known to contain a rich Upper Silurian fauna. Another instance of the difficulty of distinguishing the rocks of this most variable formation is to be found in the occurrence, first observed by Mr. Matthew, of corals and other Silurian organic remains on the Long Reach of the St. John River, in amygdaloidal ash-rocks, which are undistinguishable lithologically from those of the Huronian formation, and which, like those of Passamaquoddy Bay, had previously been referred to this horizon." (*l. c.*, p. 421.)

The relation of the rocks as given by the preceding writers has been given so far as we are able to make it out in the table appended.

In 1878 Dr. T. Sterry Hunt remarked: —

"In a paper on the Geology of St. John County, New Brunswick, published in the Canadian Naturalist in 1863, and reprinted in part in the geological report of Canada for 1870–71, page 23, Mr. George F. Matthew described, under the name of the Coldbrook group, a great mass of crystalline strata found in southern New Brunswick, to the east of the river St. John. These rocks repose on the Laurentian, and underlie unconformably the uncrystalline Lower Cambrian slates of the city of St. John, which include, near their base, conglomerates holding fragments of the Coldbrook group. From this, and from their lithological characters, these older rocks were, by Matthew, referred soon after to the Huronian series. (Quar. Jour. Geol. Soc., Nov., 1865.) They have since been found to rest unconformably upon the Laurentian, pebbles of which are contained in the conglomerates of the Coldbrook group. In the paper which contained his account of the Coldbrook group, in 1863, Mr. Matthew described a second belt of crystalline rocks similar to these, to which he gave the name of the Bloomsbury group. These, apparently resting upon the Menevian, and conformably overlaid by the fossiliferous Devonian sandstones of St. John, were, at that time, called by him altered Devonian strata. In 1869 and 1870, however, the writer devoted some weeks, in connection with Prof. L. W. Bailey and Mr. Matthew, to the investigation of the geology of southern New Brunswick, when it appeared that the Bloomsbury rocks were but a repetition of the Coldbrook group on the opposite side of a closely folded synclinal holding Lower Cambrian sediments. Accordingly, in the geological report of the gentleman just named, both of these belts were designated as Huronian; in which were now also included two other subdivisions of crystalline rocks found in that region, and previously designated the Coastal and Kingston groups. (Report of Geol. Sur., 1870–71, pages 27, 60, 64.) These Huronian rocks were traced in 1869 and 1870 along the southern coast of New Brunswick, from the head of the Bay of Fundy to the confines of Maine, as was stated by the writer in July, 1870, when these rocks 'called Cambrian and Huronian by Mr. Matthew,' and characterized by the occurrence of diorites and quartziferous feldspar-porphyries, were said to occur in Eastport, Maine, and in Newbury, Salem, Lynn and Marblehead, Massachusetts. (Amer. Jour. Science, II. 1, 89.)" (Azoic Rocks, 1878, pp. 188, 189.)

It would seem that Dr. Hunt's memory must have been at fault, since the views of Messrs. Matthew and Bailey are indiscriminately mingled with his own, while the sequence of time at which these views were presented is generally disregarded. We cannot find, in either of the papers of Mr. Matthew to which Dr. Hunt refers, any evidence that the St. John rocks unconformably overlie the Coldbrook rocks, or that the former contain pebbles derived from the latter. Mr. Matthew ex-

pressly states that there is no proof of unconformability,* and also that the deposits of the St. John group

"present a marked contrast with those of the formation on which they rest [Coldbrook Group]. Coarse fragmental beds and volcanic products are common in the latter; but among the former no conglomerate or even a grit has been detected, or any evidence of synchronic igneous action." (Quar. Jour. Geol. Soc., 1865, XXI. p. 427.)

It is also stated in the Observations on the Geology of Southern New Brunswick (1865, p. 46), that

"between the rocks above alluded to as constituting the upper member of the Coldbrook Group, and the deposits which underlie the City of Saint John, the contrast is very marked. While in the former, beds of coarse materials are almost universal, the Saint John Group is, without exception, a collection of the finer sediments. Throughout the limits of its distribution, not one conglomerate or even a grit has been yet observed; while the sandstones which occur interstratified with the slates, are usually of a fine and even texture."

If there were no conglomerates, or even grits, known in 1865 in the St. John group, and the two formations were conformable, how could Mr. Matthew, in the same paper in which these facts are stated, have referred the Coldbrook group to the Huronian, because it was unconformably overlain by the St. John group, and held fragments of the Coldbrook group in its conglomerates? The fact is, that Mr. Matthew, at that time, assigned the Coldbrook group to the Huronian, on account of its lithological characters, and because it underlaid conformably the St. John group. In fact Dr. Hunt himself was not aware of any such unconformability of the rocks in question, since he thus expressed himself in 1866, referring to the Lower Silurian: —

"The lowest member of the series as yet known, is a group of 3000 feet of black shales and sandstones, which at St. Johns, New Brunswick, is found resting conformably upon still older schistose rocks, as yet unstudied. This, which has been provisionally called the St. Johns group, has yielded numerous fossils, which have been examined by Mr. Hartt, and show the formation to correspond with the third division (Etage C) of the primordial zone." (Geol. of Canada, 1866, pp. 235, 236.)

Lithological evidence, so far as we can find, is all that is offered in support of the statement that the Bloomsbury group is "a repetition of the Coldbrook group on the opposite side of a closely folded synclinal holding Lower Cambrian sediments." The *synclinal*, the *repetition*, the *faults and overturns*, appear to be purely theoretical, and introduced to obtain conformity with that which the lithological characters seemed to

* See Dawson's Acadian Geology, edition of 1868, pp. 660, 662.

demand. Had not these rocks resembled the Huronian, no one would have ever thought that they were not Devonian; but here appeared to be some discrepancy in the theory of Delesse and David Forbes, adopted by Dr. Hunt, that certain rocks could have appeared only at one epoch in the earth's history, and to get over this difficulty an overturn of the strata was claimed. The "quartziferous feldspar-porphyries" of Eastport, which Dr. Hunt has here placed under the Huronian, have since been shown by Bailey to be at least as recent as the Upper Silurian, since they rest nearly horizontally upon Upper Silurian fossiliferous sandstone. In fact, on comparing Dr. Hunt's published views in 1870 with his explanation of them since given, it becomes quite impossible to make out what those views really were.

In 1870 the Coldbrook group, to which he assigned the felsites, was spoken of as Cambrian. (Am. Jour. Sci., 1870, (2) L. p. 89.) This paper related principally to the Terranovan, since called Montalban, and later separated into the Montalban and Taconian. The Terranovan at that time was regarded by Dr. Hunt as being in part Potsdam, and its relations to the felsites unknown. In 1871, in his address before the American Association (Proceedings, XX. p. 33), Dr. Hunt claimed that in the above-quoted paper of 1870 he held that the Terranovan was more recent than the Huronian. In 1872, in his "History of the Names Cambrian and Silurian in Geology," he claims to have held, since 1870, that the Terranovan (Montalban) and Huronian were pre-Cambrian in age, and refers to the same paper for proof of this. (Canadian Nat., 1872, (2) VI. p. 435.) In his "Azoic Rocks" (pp. 189–193) he claims to have held since 1870, referring to the same paper, that the felsites of Passamaquoddy Bay were Huronian.

According then to the original paper, and to Dr. Hunt's subsequent explanation of it, he maintained in 1870, in the same paper, that

THE FELSITES WERE CAMBRIAN.

THE FELSITES WERE HURONIAN.

THE HURONIAN WAS PRE-CAMBRIAN.

THE TERRANOVAN WAS POST-HURONIAN.

THE TERRANOVAN WAS PRE-CAMBRIAN.

THE TERRANOVAN WAS IN PART (SEVERAL THOUSAND FEET) POTSDAM.

THE GEOLOGICAL RELATIONS OF THE TERRANOVAN TO THE FELSITES WERE UNKNOWN.

From this table of conflicting views the student of North American geology can draw his own conclusions as to the value of the work done on a basis of lithological classification and speculation.

The statements previously given in Dr. Hunt's "Azoic Rocks," in regard to the geology of New Brunswick, were repeated in essentially the same form in 1879 (Proc. Am. Assoc. Adv. Sci., XXVIII. pp. 285–287; Am. Jour. Sci., 1880, (3) XIX. pp. 273–275), together with this remark regarding the lower and upper divisions of the Coldbrook group: —

"In a joint report of Matthews and Bailey in 1865, these rocks were declared to be overlaid unconformably by the slates in which Hartt had made known a Lower Cambrian (Menevian) fauna, and were compared with the Huronian of Canada."

This again is in part incorrect; for if Messrs. Bailey and Matthew declared anything in 1865, it was that the St. John group was conformable with the Coldbrook group, or nearly so, and they are so represented in their sections.* Furthermore, in Matthew's paper, published in 1865 (Quart. Jour. Geol. Soc., XXI. p. 425), the St. John group is said to conformably overlie the upper division of the Coldbrook group, and this same statement is made in the Report of Progress of the Canada Geological Survey (1870–71, pp. 59, 136).

Dr. Hunt, in 1873, remarked concerning the work of himself and Messrs. Bailey and Matthew, that he regarded the ancient crystalline rocks in Southern New Brunswick

"as for the most part the equivalents of the Green Mountain and White Mountain series, or what he calls Huronian and Montalban. These are penetrated by granites, and associated in one part with Norian rocks, but the presence of Laurentian in the region is somewhat doubtful." (Proc. Am. Assoc. Adv. Sci., 1873, XXII., B., pp. 116, 117.)

In 1875 it appears that Dr. Hunt held that the limestones in the vicinity of St. John were of Montalban age. (Proc. Bost. Soc. Nat. Hist., 1875, XVII. p. 509.) In 1878 these limestone rocks (the Portland series of Matthew) are referred to the Taconian, and the gneiss (Laurentian) to the Montalban, by the same writer. (Proc. Bost. Soc. Nat. Hist., 1878, XIX. p. 278; Preface to the Second Edition of the Chemical Geological Essays, p. xxii.; Azoic Rocks, p. 181.)

From the above it seems that Dr. Hunt would not admit as proved the presence of any Laurentian, but would take the limestones belonging according to Matthew to that formation and place them above the Coldbrook group as Montalban and Taconian. Dr. Hunt's statements seem to have no substantial basis of facts; they are mere lithological speculations. Instead of trying to ascertain whether his theories are correct,

* Observations on the Geology of Southern New Brunswick, pp. 29, 31, 50.

he assumes that they are so, and by faults, overturns, etc. endeavors to make the stratigraphy coincide with his theoretical views. The fault is always in the formation, never in the theory. According to Dr. Hunt's own statements, he had, previous to his visit to New Brunswick in 1869 and 1870, but little acquaintance with Huronian rocks. Since that, however, he has referred the felsites of Eastern Massachusetts, Pennsylvania, Missouri, and elsewhere, to the Huronian, because they lithologically resemble the rocks of New Brunswick, referred by him to that age. He ought, therefore, if he really believes that rocks of the same kind can only occur at the same epoch, to now refer all these felsites to the Upper Silurian, Prof. Bailey having shown that to be their true position, as stated on a previous page. We, however, believe that they are rhyolitic lavas and ashes, and hence that they may occur at any age and time. That they are of volcanic origin is admitted by Mr. Selwyn also.

The reader should not fail to notice that, if credit is due any one for the so-called establishment of the Huronian in New Brunswick, such credit is to be given to Messrs. Matthew and Bailey, and not to Dr. Hunt; also that the last-named gained his chief knowledge of the Huronian rocks from the study of that formation as established by Matthew and Bailey in New Brunswick, — that he was actually their pupil, and not they his, as he would give us to understand.

The various opinions held at different times by the geologists connected with the Survey of New Brunswick with regard to the classification and nomenclature of the older formation will be found presented in the tabular view (Table A.) given herewith.

NOVA SCOTIA.

Prof. Henry Y. Hind in 1870 described two series of gneissoid rocks which he regarded as probably Huronian (Cambrian) and Laurentian. (Quart. Jour. Geol. Soc., XXVI. pp. 468–479.) He gives the following as his reasons for this supposition : —

"1st. The unconformable contact of the Lower Silurian gold-bearing strata with the underlying gneissoid and schistose series.

"2nd. The unconformable contact of this gneissoid and schistose series with the old porphyritic gneiss . . . . before described as Laurentian.

TABLE OF THE PRE-CARBONIFEROU

AS ARRANGED BY MESSRS. DAWSON,

J. W. Dawson.		George F. Matthew, 1863.		George F. Matthew, 1865.		Bailey and Matthew, 1865.
1855.	Silurian.	Devonian, or Devonian and Silurian.	Portland Series.[1]	Laurentian.*	Portland.	Portland.[8]
1861.	Devonian.		Coldbrook Group.[2]			
			St. John Group.[3]	Huronian.	Coldbrook { Lower. Upper.[5]	Coldbrook.[9]
1862.	Devonian.		Bloomsbury Group.			
	Silurian. (?)		Little River Group[4] { Dadoxylon Sandstone. Cordaite Shales.	Lower Silurian.	St. John.[6]	St. John.
			Mispeck Group	Upper Silurian.		Kingston.[10] Mica Schist Group.
				Devonian.	Bloomsbury. Little River. Mispeck. } [7]	Bloomsbury.[11] Little River { Dadoxylon Sandstone Cordaite Shales. Mispeck. [1]

[1] Containing fragments of plants in the upper beds.

[2] Certainly regarded as Devonian.

[3] No proof observed that this group is unconformable either with the over- or under-lying rocks.

[4] Certain rocks afterward separated from this group under the name of Coastal were placed in the above group as Upper Devonian, because they overlie the Dadoxylon Sandstone conformably (or nearly so), and underlie the Carboniferous unconformably, while they partake of the flexures of the Devonian series.

[5] Conformably overlain by the St. John group, but on lithological grounds Huronian.

[6] No unconformability between this group and the Huronian.

[7] These three groups rest unconformably on the Laurentian, Huronian, and Silurian, and were regarded as Middle and Upper Devonian.

[8] Assigned to the Laurentian on lithological grounds. Almost entirely conformable to the overlying unquestionably Upper Devonian groups.

[9] Probably Huronian, both under- and over-lying the St. John group.

[10] Made Upper Silurian (?) on lithological and stratigraphical grounds.

[11] Entirely conformable with the Little River and Mispeck groups; not entirely so with the St. John.

* The names in this column are to be considered as applying to all beyond, except the last two columns.

FORMATIONS OF NEW BRUNSWICK,

LEY, MATTHEW, AND ELLS, 1855–1880.

ILEY AND MATTHEW, 1870–1871.	MATTHEW, 1876–1877.	BAILEY AND MATTHEW, 1877–1878.	BAILEY, 1880.	BAILEY, MATTHEW, AND ELLS, 1878–1879.	
rtland.	Portland. Coastal.	Portland.	Portland.	Lower } Portland. Upper }	Laurentian.
wer Coldbrook.[13] oomsbury.[14] gston.[15] istal.[16]	Coldbrook. Bloomsbury.	Lower Coldbrook. Upper Coldbrook. Bloomsbury. Coastal.	Coldbrook. Coastal. Kingston.[20]	Coldbrook.[22] Coastal. Kingston.[23]	Huronian.
per Coldbrook. John.	St. John. Lower Kingston.[17]	St. John.	St. John. Kingston.[20]	St. John. Kingston.[23]	Cambrian. Cambro-Silurian.
	Upper Kingston.	Kingston.[18]	Felsites of Eastport and Pembroke.[21]		Silurian.
doxylon Sandstone. rdaite Shales speck Conglomerate.	Dadoxylon Sandstone. Cordaite Shales. Mispeck Conglomerate.				Devonian.

[12] The entire Devonian series here given was laid down quietly, one group on another, with no marked unconformability or disturbance.

[13] Overlying conformably in places the St. John group, and underlying conformably the Devonian.

[14] United with Coldbrook on lithological grounds.

[15] Contains intercalated Upper Silurian strata, but Coastal overlies them.

[16] Overlying Upper Silurian and Lower Devonian strata, but from its lithological characters is placed in the Huronian.

[17] Contains pebbles derived from the St. John group.

[18] Placed here on account of palæontological evidence, although lithologically identical with the Huronian, and apparently dipping beneath that formation.

[20] In part.

[21] Lithologically undistinguishable from the Huronian, and formerly regarded as belonging to that age.

[22] No instance of the superposition of this on the Laurentian observed.

[23] In part.

[These notes represent in a brief form the statements of the geologists above quoted regarding these formations, as given in their publications and in the text preceding.]

"3rd. The unconformable contact of the gold-bearing series with the Laurentian gneiss, showing the absence of the intermediate gneissoid series, or the Huronian." (*l. c.*, p 474.)

See also Am. Jour. Sci., 1870, (2) XLIX. pp. 347–355; L. pp. 132–134, 417–422.

In order that the conclusions of Prof. Hind may properly be regarded as proved, it is necessary that the age of the gold-bearing strata supposed to be Lower Silurian or Cambrian should be ascertained, and also that the origin of the rocks in question, and their *actual*, not *supposed*, relations to one another be clearly made out, he having apparently determined the order of superposition by the dip of the foliation. Mr. Hind expressly states that his supposed Silurian strata are more altered — bearing andalusite crystals — near the so-called Huronian rocks than at a distance from them. Dr. Dawson regards the so-called gneiss of Prof. Hind as granite, and states that it is intrusive in the gold-bearing strata and Oriskany rocks. Certainly more credit should be given to Dr. Dawson's assertion than to Prof. Hind's negative evidence. (Supplement to Acadian Geology, 1878, pp. 84, 85.)

Mr. Selwyn states regarding this granitic region : —

"I have examined it in all the above-named districts, and the impression I at present have, is that it is strictly of an indigenous character, and neither an old granitoid gneissic series of Laurentian age, nor an intrusive mass. Dr. Dawson has shown (Acadian Geology, 1868) that in different parts of its course it comes successively into contact with Lower Silurian, Upper Silurian and Devonian rocks, and the manner in which these sedimentary strata are affected at the lines of contact scarcely leaves room to doubt the posterior origin of the granite ; but whether as an intrusive mass, or by the metamorphism *in situ* of the stratified rocks, (in part by a process of molecular re-arrangement of their original component particles,) is perhaps uncertain." (Geol. of Canada, Report of Progress, 1870–71, p. 265.)

Whatever the origin of the granite may have been, evidence of that origin ought to be obtained from an investigation of the relation of that rock to the adjacent ones. Dr. Dawson's statements prove most clearly the eruptive intrusive character of the granite in question, the evidence consisting not only in the induration of the rocks with which the granite comes in contact, but also in its sending tongues and dikes into them. Mr. Selwyn does not furnish any evidence to sustain his views, which seem to be the natural result of an effort to solve problems without a sufficient petrographical examination of the rocks concerned. As we have before repeatedly remarked, such metamorphism *in situ* as is here demanded needs to be proved, before it can be admitted.

Dr. Hunt thinks that the supposed Huronian of Prof. Hind belongs to the White Mountain series; but this conclusion, like most of his geological work, is purely theoretical, based on lithological resemblances. (Am. Jour. Sci., 1870, (2) L. p. 87.)

Dr. Honeyman's papers on the Laurentian age of certain rocks of Nova Scotia, in the Transactions of the Nova Scotia Institute of Natural Science, the Quarterly Journal of the Geological Society, and the American Journal of Science, appear likewise to be valueless, as his conclusions depend chiefly on lithological characters, aided by the distribution of a supposed *Eozoön*. His conclusions are, furthermore, objected to by Dr. Dawson, who states that there is neither stratigraphical, lithological, nor palæontological evidence to sustain them. The rocks in question Dr. Dawson regards as probably Lower Silurian, Cambrian, or Huronian. (Canadian Naturalist, 1879, (2) IX. pp. 1–16.)

According to Mr. Edward Hartley, the Coal Measures near New Campbelltown, Cape Breton, stand vertical, or nearly so, within one hundred feet of syenite and "limestone highly altered serpentinous and crystalline." The dip of the Coal Measures diminishes on receding from the syenite, until they assume a nearly horizontal position (dip 5 or 10 degrees). Since the syenite and limestone resemble the Laurentian, Mr. Selwyn writes: "From the foregoing facts it appears that the Coal Measures in Cape Breton are in direct contact with rocks of Laurentian Age."

The present writers, however, think that nothing of the kind has been proved. It has been simply shown by Mr. Hartley that the Coal Measures are seen highly tilted within fifty or one hundred feet of limestones and syenite of unknown age. (Geol. of Canada, Report of Progress, 1870–71, pp. 4, 5.)

Later, Mr. Charles Robb, in an examination of the same region, states: —

"The existence of a fault or complication of faults here seems to be proved beyond a doubt, and the occurrence of a band of calcareous and magnesian rocks of varying thickness, between the Lower Carboniferous and Productive Coal-measures on the one hand, and the syenite on the other, is also clearly established."

No eozoönal characters were found in the limestone on microscopic examination. (Report of Progress, 1873–74, p. 174.)

Mr. Robb later gave a much fuller account of the district, with a map of the same. He found a conglomerate containing pebbles of syenite in the Lower Carboniferous rocks, and some of the strata appeared to have been inverted. (Report of Progress, 1874–75, pp. 251–262.)

In commenting upon Mr. Robb's work, Mr. Selwyn remarks : —

"The examinations recently made by Mr. Robb at Kelly Cove on the Great Bras D'Or Lake show that a similar series of crystalline rocks, — magnesian limestones, serpentine, &c., — occur there between the Carboniferous series and the great mass of syenite, which has been supposed to be of Laurentian age ; but which will, I think, more probably prove to be an *intrusive* mass nearly corresponding in age with the great central granitic axis of Nova Scotia, which is undoubtedly pre-Carboniferous and post-Devonian." (*l. c.*, p. 9.)

This is certainly a striking change in Mr. Selwyn's opinion since 1871. The evidence, however, is strongly in favor of his later views. Mr. Hugh Fletcher, from more extended labors in Cape Breton, rendered it quite evident that in some localities the syenites and felsites are older than some lower Silurian rocks, hence probably Azoic. He relies on lamination solely to prove the sedimentary origin of the rocks in question, and on almost every page shows by his work that he has no knowledge of the characters of eruptive rocks, or of the methods of proving in the field whether the rocks in question are or are not eruptive. His statements concerning their origin are therefore valueless.

The St. George limestone, which he thinks may possibly be Huronian, — although he has classed it as Laurentian, — is said to contain pebbles apparently derived from the syenites and felsites. (Reports of Progress, 1875–76, pp. 371–388 ; 1876–77, pp. 405–428 ; 1877–78, pp. 3–10, F.)

The age of the limestone was not determined any farther than that it was shown to be older than the Carboniferous ; it was simply assumed that it was Azoic. Concerning the Huronian in Nova Scotia, Principal J. W. Dawson remarks : —

"There is no good evidence that the Cobequid series and its equivalents in Pictou and elsewhere are older than the Lower Silurian. There seems, however, good reason to class as Huronian, or at least as Lower Cambrian, the rocks of the Boisdale Hills in Cape Breton, which Mr. Fletcher finds to underlie the fossiliferous Cambrian of that region, and which are more quartzose and micaceous than the rocks of the Cobequid series. It is not impossible that rocks of this age may also occur in the vicinity of the Cambrian beds found at Miré. We may also conjecturally class as Huronian the chloritic rocks of Yarmouth." (Supplement to Acadian Geology, 1878, p. 88.)

In the same work Dr. Dawson also states regarding the Laurentian : —

"Dr. Honeyman and Prof. Hind have suggested the Laurentian age of certain rocks as Arisaig, in the Cobequids, and associated with the coast Meta-

morphic series, but I do not regard the evidence of this, either from fossils, mineral character, or superposition, as conclusive, and must refer for it to the memoirs of these gentlemen in the transactions of the Nova Scotia Institute, and the Journal of the Geological Society of London. I must, in like manner, decline to receive as of Laurentian age the felsitic and other rocks of Cape Breton, referred to this system by Mr. Fletcher in the latest Report of the Geological Survey. I would except those of St. Anne's Mountain, the lithological resemblance of which to the Lower Laurentian of Canada is indisputable, and the evidence that they may be of this age has certainly been much strengthened by the recent observations of Mr. Fletcher. Specimens, and the observations of Mr. Brown and Mr. Campbell and others, induce me also to believe that in the little island of St. Paul, and in some parts of Northern Cape Breton, we may have a continuation of the rocks referred by Mr. Murray to the Laurentian in Newfoundland. With these exceptions, I have not seen in Nova Scotia, unless in travelled boulders, any rock that I could believe to be lithologically equivalent to the Laurentian of Canada, nor have I found any stratigraphical evidence of the occurrence of such rocks." (*l. c.*, pp. 89, 90.)

The condition of the question in Nova Scotia can be briefly summed up as follows. In one locality it is probable that some rocks — of, in part at least, doubtful origin — are of Lower or Pre-Silurian age. There is no evidence showing that they should be subdivided into any of the supposed pre-Palæozoic systems, other than lithological, and the finding of some pebbles in a limestone, supposed (not proved) to be the same as the rocks it was desired to place in an inferior position. In fact, beyond the evidence of the pebbles, no proof has been furnished that would justify us in placing any of the rocks of Nova Scotia below the recognized fossiliferous portions.

NEWFOUNDLAND.

The first report of the Geological Survey of Newfoundland made under the general direction of the head of the Canada Survey, Sir William Logan, bears date April 11, 1865. Previous to this, however, Prof. J. B. Jukes made a geological reconnaissance of the island, under governmental authority. This was during the years 1839 and 1840. As Professor Jukes made no attempt to assign names, other than local, to the formation below the Carboniferous, it will not be necessary to take his work into consideration in the present connection.

Mr. A. Murray, in his report to Logan of what was done during the year 1864, recognizes the Laurentian Series as occurring on the northern peninsula of Newfoundland. He gives the following table of the sequence and distribution of the rocks of that region. (*l. c.*, p. 8.)

I. Laurentian Series.
II. Lower Silurian Series. { Potsdam Group.
III. Upper Silurian Series. { Quebec Group.
IV. Devonian Series.

After describing the rocks assigned to the Laurentian, which were found to be exclusively of a gneissic character, he adds as follows : —

"The rocks which have thus been described are considered Laurentian, not merely from the lithological resemblance which they bear to the strata of that series in various parts of Canada, but also from the relation they are seen to have to the Lower Silurian series, which unconformably covers them up in the northern part of the peninsula. . . . . In Canada the Laurentian gneiss is in some parts interstratified with enormous bands of crystalline limestone. . . . . None of these bands have been met with among the gneiss of the northern peninsula." (*l. c.*, pp. 10, 11.)

In the Report upon the Geological Survey of Newfoundland for the year 1868, Mr. Murray introduces into the series of formations of that island an "Intermediate System," which he supposes to be the "equivalent of the Cambrian of England, and the Huronian of Canada." This series he divides into seven distinct groups, admitting, however, that "there are many repetitions of the same strata," and that "a large portion of the country is concealed by superficial deposits of gravel and boulders." The total thickness of the strata thus divided is given at 11,370 feet, the rocks being, with the exception of the upper portion, chiefly slates, and the reason for this manifold division of the series not being apparent in the description of the same. About the middle of the series, in group *c*, "fossil forms, supposed to be of the genus *Oldhamia*," were obtained. In group *d*, also, "some obscure organic remains, resembling the fossils found in *c*," were found. The order of superposition of these rocks was determined by observations made along a section from St. John's to the northern side of Great Bell Isle in Conception Bay. In a note added to the English reprint of the series of Newfoundland geological reports (published by Stanford, in London, in 1881), it is said that the fossil forms "supposed to resemble the *Oldhamii* of Bray Head" were pronounced, on examination by Mr. Billings, the late palæontologist of the Survey, to be undeterminable. "He doubted their organic origin altogether." (*l. c.*, p. 144.)

In the Report of the Geological Survey [of Newfoundland] for the year 1872, Mr. Murray notes the discovery of fossil forms in the Huronian rocks of St. John's, which, according to him, "appear to mark out a particular zone or horizon of the formation, which is limited to the subdivision (*d*) of No. 2 Section" of the Report for 1868. These fossils are the *Aspidella* (misprinted *Aspidilla* throughout the report for 1872) *Terranovica* and the *Arenicolites spiralis*, described by Billings in the "Palæozoic Fossils" of the Canada Geological Survey, Vol. II. Part I. pp. 76, 77. The presence of the *Aspidella* was considered by Mr. Murray as being of "marked value as an indicator of the horizon, no form bearing any resemblance to that fossil having ever been recognized in the rocks of the upper series. Nor are they known to exist in any of the strata, by which the slates (*d*) are underlaid." (*l. c.*, p. 17.)

In the Report of Progress [of the Geological Survey of Newfoundland] for the year 1873, the presence of "labradorite and other anorthosites" in the gneissic rocks of certain localities is said to "give rise to the supposition that they belong to the upper or newer Laurentian Series," while angular boulders and fragments of white crystalline limestone are considered to be "suggestive of the proximity of the upper members of the lower series." This is the first intimation that the Laurentian is to be divided into two or more groups, and seems to be merely an endeavor to correlate the older formations of Newfoundland with those of Canada, on a purely mineralogical basis, and on extremely imperfect evidence.

That certain stratified rocks are unconformable with a lower granitic and gneissic formation, called Laurentian, is evident from the facts stated in the Newfoundland reports. That these strata belong to the Primordial or Potsdam division of the Lower Silurian is also made apparent by the character of the fossils which they contain. That these Primordial rocks may be developed to a very great thickness is also rendered probable; although it is not unlikely that a more thorough study of the region would considerably reduce that amount, the region being one difficult of exploration, much disturbed, and largely covered by superficial detritus.

In the Report of Progress [of the Geological Survey of Newfoundland] for the year 1881, the discovery of the *Aspidella* and the *Arenicolites* is again alluded to, as offering "great facilities for the ready recognition of the Huronian when tracing out the structure which, otherwise, would be extremely difficult." The value of the evidence based on the presence of these supposed fossils, as establishing a new system between the Primordial and the Laurentian, will be discussed farther on. At pres-

ent it need only be remarked that the published sections do not furnish the desired proof of the unconformability of the "Intermediate Series" with the overlying Primordial.

LABRADOR.

In 1863 the gneissoid rocks of Labrador were assigned by the Canadian survey to the Laurentian. In 1865, Prof. A. S. Packard, Jr. gave some account of the geology of the coast of Labrador. It seems at the beginning he mistook for syenite some diabasic rocks, and thought, from finding some pebbles enclosed, that it was formed from a conglomerate. He evidently was not aware that eruptive rocks frequently enclose pebbles that they have picked up. Indeed, it is probable that under the name Syenite Prof. Packard has united very diverse rocks. He assigns some quartzites doubtfully to the Huronian, saying: "Nowhere was I able to see the juncture of this rock with the Laurentian gneiss. . . . . At no point was I enabled to observe whether these quartzites rest unconformably upon the older Laurentian gneiss, though inclined to think so. . . . . The Canadian Geologists likewise state that the strata of the Huronian system have not been observed resting *directly* on tilted Laurentian rocks; it is as yet a matter of hypothesis." Prof. Packard evidently assumed that the foliation of the gneiss or granite was synonymous with stratification.

He pointed out the presence of the labradorite rocks forming the Upper Laurentian of Logan and the Norian of Hunt, but he (Packard) does not seem to have observed its relations to the other rocks. He however found part of it in overflows which he supposed resulted from a refusion of the labradorite rock. His observations point rather to an eruptive than to a sedimentary origin for this "norite." (Memoirs of the Bost. Soc. Nat. Hist., 1868, I. 213–218.

Prof. Packard's Huronian Dr. Hunt regards as Laurentian, but accepts the labradorite rock as Norian. (Amer. Jour. Sci., 1870, (2) XLIX. p. 182.)

Prof. H. Y. Hind later described the Geology of Northeastern Labrador; but, as before, the rocks were referred to the Laurentian on lithological grounds. No evidence was given to show the relations of the so-called Upper Laurentian to the Lower Laurentian, but all rested on

theoretical grounds. (Canadian Nat., 1878, (2) VIII. pp. 227–240, 262–278.)

In 1876 Mr. D. F. H. Wilkins illustrated in a paper upon Labrador some of the methods employed in the study of crystalline rocks. The supposed formations were determined by lithological characters, the foliation taken as the lines of stratification, and an apparent dike regarded a representative of the Norian. He says: "The stratification lines are very often so obscure that it is almost impossible to say whether the rocks are metamorphic or eruptive"; and of the Norian at one locality, that it consists of "red-weathering, gray hyperite in a bed two feet thick, overlaid by four feet of whitish gneiss . . . ., seen to repose, at low tide, upon the underlying red gneiss of Lower Laurentian age." (Canadian Nat., 1878, (2) VIII. pp. 87, 88.)

Thus far we have found no evidence except lithological in support of the ages to which the crystalline rocks of Labrador were assigned.

MAINE.

The geological survey of Maine, under Prof. Chas. H. Hitchcock, developed nothing of value as determining the question whether the Azoic system existed in that State. No evidence bearing on this question other than lithological was furnished.

Dr. Hunt in his Geognosy of the Appalachians infers from lithological characters and difference in dip that the "mica schists and gneisses" are of Montalban age, while the "greenish chloritic and chromiferous schists" in the vicinity of Portland are Huronian and older than the gneisses. (Presidential Address, 1871, p. 10.)

Prof. Chas. H. Hitchcock objected to the views of Dr. Hunt, holding that, while the rocks in question were Montalban and Huronian, the Montalban was the older, and the Huronian at this point was deposited upon it. He states that "at the line of junction as observed in Deering, the two groups of rocks possess exactly the same inclination," and declares that, if in their natural position, the gneiss underlies the schist. He acknowledges that the only way these formations have been identified is by lithological characters, remarking that

"Logan, in 1855, described a system of rocks overlying unconformably the Laurentian gneisses about Lake Huron, which were distinguished by means of

lithological characters. All geologists, therefore, who use the name Huronian, of necessity practically adopt this principle, though perhaps insensibly. We do not claim that a talcose rock can never be found in any other system than the Huronian, nor that gneiss may never be interstratified with the hydromicas. Professor Dana's recent paper shows that gneisses, quartzites and limestones are interstratified in the Lower Silurian of western New England. . . . . In no instance would we claim that mineral character is sufficient to distinguish systems without a study of the relations of the strata. We may sometimes generalize, and believe that rocks of similar mineral character must be of the same age, but such speculations always provide for confirmation by a study of the strata." (Proc. Am. Assoc. Adv. Sc., 1873, XXII. pp. 166, 167.)

We shall see that in New Hampshire Prof. Hitchcock relied entirely on lithological evidence, evidently not following the views here advocated.

In his paper on Granites and Granitic Vein-stones Dr. Hunt referred many of the granites (gneisses) and mica schists of Maine to the Terranovan or White Mountain series, but on lithological grounds. (Am. Jour. Sci. 1871, (3) I. p. 182.)

In two more recent papers by Messrs. Hitchcock and Huntington certain rocks in Northern Maine are regarded as Laurentian and Huronian, if not Montalban; but this decision rests solely on lithological evidence, not the slightest proof being given that the rocks in question may not be much more recent than the Azoic, and of the same instead of different ages. (Proc. Am. Assoc. Adv. Sci., 1873, XXII. pp. 205–214; 1877, XXVI. pp. 277–286.)

Thus far no evidence has been given that proves the pre-Silurian age of any rocks in this State, all the evidence thus far advanced being based exclusively on lithological characters.

NEW HAMPSHIRE.

In this State we have principally to do with the writings of Messrs. Hunt, Huntington, and Hitchcock, these being the geologists who have especially interested themselves in establishing subdivisions in the supposed Azoic rocks of that State. It is in the publications of Prof. C. H. Hitchcock, State Geologist of New Hampshire from 1869, however, that we find the larger part of that which touches the questions here before us.

In stating the results obtained by the Canada Geological Survey, as detailed in the Report of Progress for 1847–48, Dr. T. Sterry Hunt remarked that to the "Chemung and Portage group of New York, with the old red sandstones, ... may perhaps be referred in part the rocks of the White Mountains." (Am. Jour. Sci., 1850, (2) IX. p. 19; Proc. Am. Assoc. Adv. Sci., 1849, II. pp. 333, 334.)

In 1863 he wrote: —

"It is moreover probable that the rocks of New Hampshire, including the White Mountains, are altered strata of Devonian age." (Geol. of Canada, 1863, p. 598.)

In 1867 the White Mountains were again referred to the Devonian by Dr. Hunt. (Esquisse Géologique du Canada, p. 23; Bull. Soc. Géol. France, 1867, (2) XXIV. p. 687.

Prof. J. P. Lesley, in 1860, stated that he had a

"growing conviction that the range of the White Mountains would prove to be *synclinal* instead of anticlinal, and therefore of probably Devonian age. . . . . Ascending Mount Osceola . . . . the bridle path mounts over successive outcrop ledges of perfectly horizontal plates of granite, as evidently and regularly bedded as any of the sandstone masses of the Alleghanies, the bed planes not being at all disguised by the cleavage planes. Between these plates of granite lie plates of unchanged dark blue sandstone; a rock which at the cascades . . . . has been mistaken for greenstone trap." (Proc. Acad. Nat. Sci. Phil., 1860, XII. pp. 363, 364. Mining Magazine, 1861, (2) II. pp. 99–101.)

The probable truth in this is, that Prof. Lesley mistook some old basaltic dikes for sandstone, and the concentric lamination of the granite for stratification.

Dr. Hunt, in 1878, stated that Logan suggested that the rocks of the White Mountains were "probably altered Devonian strata" (Azoic Rocks, pp. 86, 87, 182); while, in 1861, he said: —

"The White Mountains as we suggested in 1849 (this Journal, [2], IX, 19), are probably, in part at least, of Devonian age, and are the representatives of 7000 feet of Devonian sandstone observed by Sir William Logan in Gaspé. Mr. J. P. Lesley has more recently, after an examination of the White Mountains, shown that they possess a synclinal structure, and has adduced many reasons for regarding them as of Devonian age." (Am. Jour. Sci., 1861, (2) XXXI. p. 403.)

In 1870 it would appear that, under the name Terranovan, they were regarded by him in part at least as Potsdam. (Am. Jour. Sci., 1870, (2) L. pp. 83–90.)

In the First Annual Report of the New Hampshire Geological Survey, 1869, Prof. C. H. Hitchcock divided the rocks then examined as follows : —

"Gneissic, Granitic or White Mountain Series.

Staurolite Schists
Lower (mostly green) Schists
Copper Belt
Clay Slate
Auriferous Conglomerate
} Quebec Group.
Upper Schists."

Prof. Hitchcock in that Report states that

"there are two general divisions . . . ., first the granitic and gneissic rocks which appear to be older and consequently to underlie the formations of the second or Quebec group — the true auriferous strata. The name Quebec is that applied by Sir W. E. Logan, of Canada, to rocks . . . . shown to constitute a new group, not present in the New York series, but lying between the Calciferous Sandrock and the Chazy Limestone." (*l. c.*, p. 17.)

No evidence is given to show that the rocks belong to the Quebec group, and that the granite is not eruptive, nor are its relations to the supposed Quebec group stated. All is based upon theoretical grounds.

In the Second Annual Report, 1870, the rocks of New Hampshire are arranged as follows : —

"1. *White Mountain or Gneissic series*, subdivided into

1. Normal Gneiss.
2. Ferruginous Gneiss.
3. Granitic Gneiss.
4. Feldspathic Mica Schist.
5. Andalusite Gneiss.
6. Chiastolite Slates.
7. Granite.
8. Syenite.
9. Porphyritic Granite.
10. Quartzites.
11. Limestones.
12. Soapstones.

"Little doubt remains as to the Eozoic or pre-Silurian age of this entire series."

"2. *Sienite of Exeter and Dover.*

"There appear to be sienitic rocks of probable Laurentian age, equivalent to the Quincy sienitic group of Massachusetts, ... in the towns of Exeter and Dover. They form, apparently, an anticlinal mass, overlaid by the Merrimack slates."

"3. *Porphyritic Granite.*

"Common granite full of large crystals of feldspar. . . . . Some portions of it have evidently been injected, while the arrangement of the feldspathic crystals in parallel lines leads to the suspicion of stratification in other cases."

"4. *Common Granite.*

"The granite of New Hampshire seems to have originated at five different periods. First are the (*a*) indigenous and (*b*) eruptive granites of the White Mountain series; second, the (*c*) indigenous granites of the Merrimack group, in which none of the eruptive class have yet been seen; third, the (*d*) indigenous and (*e*) eruptive granites of the Coös and calciferous mica schist groups."

"5. *Merrimack Group.*

"They probably belong to the earliest Silurian series."

"6. *Quebec Group.*

"Lower Silurian, according to Sir William E. Logan."

"7. *Coös Group* of slates, schists, quartzites, etc.

"It appears clearly to overlie the White Mountain *veins* unconformably."

"8. *Calciferous Mica Schist.*

"9. *Clay Slates.*

"8 and 9 seem to be limited outliers in New Hampshire." (*l. c.*, pp. 31–34.)

In the Third Report, for the year 1870, it is stated that

"the White Mountain rocks are believed to belong to two great systems, the Gneissic and the Coos Group. The first are, for convenience, called the White Mountain series. . . . . These rocks appear to underlie the Coos group, and are therefore older. The presumption is that they are entirely Eozoic, though it is not clear whether they are to be considered as the equivalent of the Laurentian of Canada, or more nearly the age of the Cambrian of Great Britain as restricted by the Government Survey. . . . . Its satisfactory reference to the Eozoic series will enable us to clear up the obscurities of New Hampshire geology."

The Coös group was placed as before above the White Mountain series, and, "judging from fossils in Nova Scotia, this group is not far from the St. Johns slates in age." (*l. c.*, pp. 9–11.)

In the next Report, — that for the year 1871, — some changes were made in the general arrangement of the rocks, which were classed as follows: —

"1. Porphyritic Gneiss.

"We suppose this to be the oldest formation among the mountains. Geologists speak of a rock of this character as common in the laurentian in various parts of North America and Europe."

"2. Bethlehem Gneiss.

"It is usually granitic, so much so that it has always been called granite heretofore. . . . . Lying between outcrops of porphyritic gneiss the natural inference is that it is a synclical, and therefore newer, while the strike indicates a very great antiquity judging from the same phenomenon elsewhere. . . . . If the anticlinal structure is persistent, evidence may be afforded that this peculiar gneiss is older than No. 1."

"3. Gneiss.

"4. White Mountain or Andalusite Gneiss.

"It seems to be newer than Nos. 1 and 2, but the relations to the granites and norian are yet to be made out.

"5. Common Granite.

"The joints passing through this rock are both horizontal and vertical. . . . . East of Saco the Andalusite gneiss seems to have been cut by it."

"6. Trachytic Granite.

"Above No. 5, with the same horizontal appearance."

"7. Brecciated Granite.

"The rock is irregular in arrangement as if thrust up from below. As it contains no fragment of the common and trachytic granite, we have concluded it to be more ancient than either of these granites, but newer than the porphyritic gneiss. The two areas are also probably connected beneath the Pemigewasset valley under the common coarse granite, which either flowed in above the breccia or was deposited upon it quietly in some other way."

"8. Norian.

"This includes several areas of labradorite rock, including compact felsites, breccias and syenites."

"9. Clay, Slate and Quartzites.

"10. Coos Group."

Concerning the age of the Norian and some others of the preceeding divisions, Prof. Hitchcock remarks: —

"All will agree that the mineral labradorite belongs to the original laurentian system, and therefore by its discovery in New Hampshire will be satisfied that some of our crystalline rocks belong to the older series of the Eozoic, and not the Paleozoic. Hence the prevalent opinion respecting the age of the New England metamorphic rocks must be changed to conform with the discovery of labradorite in our state. . . . . Our conclusions as to the absolute and relative ages of the New Hampshire formations depend upon the reference of some of them to the Norian system of Hunt." (*l. c.*, pp. 4–10.)

Dr. Geo. W. Hawes regarded the Norite rock as eruptive, saying: —

"At some points the rock possesses all the structure of an eruptive mass, and when in other places this is not found, the evidence furnished by more

favorable localities, as well as that furnished by allied rocks in other lands where they have been more thoroughly investigated, must at present be decisive." (Geol. of New Hampshire, III., Part IV. p. 165.)

This rock was accepted by Dr. T. Sterry Hunt as Norian in 1873 (Proc. Bost. Soc. Nat. Hist., 1873, XV. p. 310), but in 1878 he remarked : —

"The labradoritic rocks in the White Mountains, which had by Hitchcock been referred to norite, are now found by him to be eruptive masses." (Azoic Rocks, p. 161.)

In a paper by Prof. Hitchcock (Am. Jour. Sci., 1872, (3) III. pp. 43–47), on the "Norian Rocks in New Hampshire," the following is advanced to show their sedimentary origin : —

"The first rock seen is a gneiss with nodular orthoclase, dipping by compass about 80°, S. 70° W. The strata are indicated by folia of a dark hypersthenic mineral, often forming bunches or nodules. Jointed planes dipping about 25° westerly might be mistaken for strata.* One might be so easily deceived, that it seems as if they must be the planes described at the Cascades and on Mount Osceola by J. P. Lesley. . . . . A few rods higher up the stream . . . . the first ledge of the labradorite rock appears. . . . . It is a perplexing matter to determine the lines of stratification, as the outcrops are divided by two prominent sets of jointed planes, either of which might be called layers of deposition, the rock being essentially homogeneous. One set dip about 20° northerly and are the most numerous. The other dip about 75°, W. 10° S. The latter correspond better in position to the gneissic strata first seen than the former."

In the Report for 1871, published in the summer of 1872, we have the following statements regarding the same rocks : —

"The first rock seen was called gneiss with nodular orthoclase, with its supposed strata dipping by compass 80° S. 70° W. . . . . the presumption arises that these so-called strata may be bands of mica whose planes do not correspond with those of accumulation, but have been superinduced during the metamorphism of the rock. The jointed planes dipping about 25° westerly would be those of stratification, if the rock is stratified. These were pointed out by J. P. Lesley. A few rods up Norway Brook appears the first ledge of the Ossipyte [the labradorite or Norian rock]. . . . . Considered as an isolated case it is difficult to determine the planes of stratification since two prominent sets of jointed planes exist, either of which might be taken for strata. One set dip about 20° northerly, and are the most numerous. The other dip about 75° W. 10° S. As the latter correspond better in position with the supposed strata of nodular gneiss, it was thought they indicated the proper lines of

* Same statement in Atlas of New Hampshire, 1877, p. 11.

deposition. The former, however, are what appear at the first glance to be the strata, and as by this interpretation the position of the rocks at Waterville will correspond with that in Franconia about the Lafayette range, our former ideas must be modified." (*l. c.*, pp. 15, 16.)

Again, in a paper read a few months later, Prof. Hitchcock said : —

"In ascending from 'Beckytown' the first rock met with is 'trachytic granite.' This I called 'gneiss with nodular orthoclase' in my first sketch, with seams or strata dipping (by compass) 80° south, 70° west. . . . . A careful examination of this granitic rock in numerous localities leads to the conclusion that it is a true erupted granite and not a gneiss ; though it is possible the present case may be an exception. . . . . The first ledge of *ossipyte* appears a few rods higher up. . . . . The rock seems to be stratified, the planes dipping about twenty degrees northerly. . . . . The importance of this discovery may be best appreciated by remembering that the presence of the lime feldspars affords a strong presumption that these rocks are Eozoic, and not metamorphic Paleozoic formations. It seems to be generally admitted by geologists that these feldspars are confined to the older rocks, except as found in eruptive trappean and volcanic masses." (Proc. Am. Assoc. Adv. Sci., 1872, XXI. pp. 135–151.)

In the second volume of the Final Report on the Geology of New Hampshire, pages 210, 214, 257, 258, 266, the following statement is made regarding the labradorite and its associated rocks : —

"None of the Labrador areas, whether in America or Europe, have yet been carefully studied stratigraphically, so that we have not the means of knowing their thickness. The lines of iron ore and other foreign minerals better agree with the idea of stratification than to suppose the masses are eruptive. In the study of New England rocks, the labradorite aids us greatly, since most geologists are prepared to accept it as indicating formations of Eozoic date ; and, if these triclinic feldspar layers rest upon strata formerly thought to be Paleozoic, they render it probable that both the underlying and contiguous masses belong to very ancient systems. . . . .

"A few rods above [Beckytown] is an exposure of the same rocks with those seen at the falls, dipping 80° S. 10° W. The strata are indicated by folia of mica and a little of a dark hypersthenic mineral, often forming nodules. There are jointed planes, also, with a dip westerly of 25°. . . . . Between Norway and Cascade brooks there seems to be an anticlinal axis in the porphyritic gneiss. At first I was satisfied that this rock was gneiss, but did not recognize its true place with the porphyritic group. Subsequently I referred it to the 'trachytic' or Albany granite, but a reëxamination in 1875 shows that it belongs to the oldest of our formations, and is distinctly stratified, traversed by trap dykes and narrow banded veins of quartz. These exposures do not occupy more than two hundred feet of distance. A few rods up Norway brook appears the first ledge of the ossipyte. . . . .

"Considered as an isolated case, it is difficult to determine the planes of stratification since two prominent sets of jointed planes exist, either of which might be taken for strata. One set dip about 20° northerly, and are the most numerous. The other dip about 75° westerly. More definitely, the following are the supposed strata dips seen in ascending; about 20° to N. 26° W., N. 86° W., N. 34° E., and N. 46° W. The joints have these strikes, N. 22° W., N., and S. . . . . The evidence is plain that the Labrador system does not include, besides the triclinic feldspars, the porphyries and all the Pemigewasset granites. Hence the statements respecting the nature of the events transpiring in the Labrador period, — given in the chapter upon the physical history of the strata, — pertain to a later epoch. . . . . We are therefore led to believe that the labradorites alone represent the Labrador system, and, as thus limited, it has been described. . . . . There are seven small areas of it, cut by a sort of 'sienite' containing triclinic feldspars, and therefore supposed to close the period. . . . . The reality of the system is not affected by the removal from it of these various porphyries and granites. Their elimination makes the correspondence perfect between the New Hampshire and Canadian areas, thus establishing more firmly the existence of the series. Some difference of opinion may exist among geologists as to the relations between the Montalban and Labrador systems. . . . . The labradorite rocks, with a very moderate dip, rest unconformably upon the greatly upturned edges of the Montalban schists, as if there had been large upheavals at the close of the Montalban period, and comparatively little disturbance since. . . . . The facts as interpreted are of great consequence, since they fix the geological horizon of the whole Atlantic system, while considerations of a stratigraphical character confirm this impression. . . . . The discovery of the Labrador system, overlying the most abundant and characteristic White Mountain strata, makes it clear that the latter are older than the former, which are confessedly Eozoic."

In the Final Report on the Geology of New Hamphire, Vol. II. p. 667, Prof. Hitchcock remarks as follows: —

"The Labrador system, if present in New Hampshire, is in very limited amount. Recent investigations make it difficult to say that the labradorite rocks are not of eruptive character. They have the composition of dolerite; and certain exposures of them upon Mt. Washington are surely injected dykes. Hence great doubt arises whether the larger area of Waterville really represents the Labrador system of Canada. At all events its age is great, for these dykes cut through Montalban strata. This dolerite may be regarded as one of the oldest eruptive rocks in the state, coming to the surface in what was the Labrador age of the world."

Resuming the Report for 1871, we find the relative geological position of the formations to be stated as follows: —

"The sections given of the common granite, trachytic granite and the norian series (or at least certain felsites,) seem to determine their relative positions,

the last being at the top. The brecciated granites of Franconia seem to be older than any of these, and to underlie them. . . . . If these points are assumed, the porphyritic gneiss can be shown to be at the bottom of the series, for it lies outside of the lowest of them. . . . . We cannot as yet locate the andalusite gneiss, save that it is newer than the porphyritic bands as shown at Moosilauk. . . . . The Coos group of Littleton and Lisbon passes around the west end of the Bethlehem gneiss, showing that the latter existed before either the deposition or elevation of the former. This indicates that the whole of the White Mountain rocks are more ancient than the Coos and Quebec groups of the Connecticut valley." (*l. c.*, pp. 25–27.)

In the Report for 1872, the Quebec group of the earlier reports is assigned to the Huronian. The Porphyritic group is described as consisting

"mainly of gneiss full of large crystals of orthoclase feldspar, associated with ferruginous and other bands. It is regarded as the oldest of all the formations in the State for these reasons:

"1. The principal range is flanked on both sides by similar varieties of gneiss, and later series of rocks in the same order. The newer groups being outermost, the anticlinal rather than the synclinal structure is suggested, and hence the greater antiquity of the central range.

"2. This rock is apparently covered by the other members of the gneiss series in the northern part of the State.

"3. The lithological chamber [? character] corresponds with that of known Laurentian strata in Canada, North Carolina, and elsewhere." (*l. c.*, p. 11.)

Of the "Concord granite" Prof. Hitchcock says: —

"This rock is not a proper granite. There is an arrangement of the particles of mica along parallel planes, which allows the rock to split readily. These we regard as strata." (*l. c.*, p. 12.)

In 1872 Professor Hitchcock presented the following classification of the rocks of New Hampshire: —

"I. Eozoic.

"1. *Laurentian*, including (*a*) porphyritic gneiss; (*b*) White Mountain series, or andalusite gneiss; (*c*) Bethlehem, or talcose gneiss; (*d*) gneiss of Lake Winnipiseogee Basin; (*e*) gneiss on both flanks of the porphyritic variety in the south part of the State, subdivided by bands of quartzite, — this carries the Concord and Fitzwilliam granites, and is probably the beryl-bearing series also; (*f*) range of gneiss between Whitefield and Milan, considerably hornblendic.

"2. *Norian*, including (*a*) common granite; (*b*) trachytic granite; (*c*) four bands of felsite, both labradorite and orthoclase.

"3. *Exeter syenites*, including those cutting the Norian at Waterville, Mount Monadnock, opposite Colebrook, Redhill, &c.

"4. *Huronian.* The talcose schist series along Connecticut River, and in the north part of Coös County.

"5. *Older Cambrian?* Includes Coös and Merrimack groups, and probably the 'Calciferous Mica Schist' of Vermont Survey.

"II. PALEOZIC.

"Helderberg limestones.

"Clay slates."

In discussing these formations it is later stated as follows: —

"If these granites behave like a stratified formation, of course the question is at once raised whether they should not be regarded as true strata. The answer cannot be given from position merely, since it is not uncommon to find sheets of trap or lava holding a perfectly analogous position. We have preferred to think of the White Mountain country at the end of the Laurentian period as an immense basin, upon which there was an overflow of common granite. Being liquid, it spread itself out like water, assuming a horizontal surface. After a while there was an eruption of trachytic granite, which spread itself in the same way. Subsequently the felsites were formed above them conformably. It would be natural to regard these granites, and felsites as belonging to one period, the Norian. The limits of this system have not been fixed; and it seems as if in New Hampshire it should commence in the common granite, and end with the red orthoclase felsite. . . . .

"If the felsite series is of the age of the Upper Laurentian or Labrador of Logan, then by the law of superposition the strata underneath the common granite are Lower Laurentian. Observation showed us, at this phase in the development of the White Mountain structure, two gneisses and a breccia underneath the granite sheet. The most important is the '*Porphyritic gneiss*,' or granite sometimes. This is a gneiss having large crystals, usually one and a half inches long, of orthoclase, arranged in layers in the mass, with the longer axes parallel to one another. These we conceive to be the strata. . . . .

"The description of the Laurentian rocks in Canada and Europe make mention of large quantities of porphyritic gneiss; hence we feel warranted in referring these lower schists to the Laurentian system. We have yet found nothing older in the state. . . . .

"Our explorations have brought to light the existence of ten distinct periods, whose records can be traced upon the scarred sides of these highest mountains of New England. . . . .

"If our limited opportunities have led to such unexpected results, what may we not look for when the geological structure of the entire metamorphic area of New England has been carefully studied!" (Proc. Am. Assoc. Adv. Sci., 1872, XXI. pp. 134–151.)

In 1873 Prof. Hitchcock remarks that the evidence of the inferior position of the White Mountain or andalusite gneiss

"to the Labrador group is very decided. . . . . In the valley of Dry or Mt.

Washington River, ... there is a limited synclinal of ossipyte resting upon the upturned edges of the andalusite gneiss." (Proc. Bost. Soc. Nat. Hist., 1873, XV. pp. 304–310.)

In the second volume of the New Hampshire Geology, Prof. Hitchcock writes as follows : —

"Another important doctrine relates to the identification of formations in our field of labor by means of mineral characters. . . . . The style of similarity made use of for identification is better shown in the porphyritic gneisses. There are over thirty areas of porphyritic gneiss, in which the feldspar crystals are very conspicuous for their size, the rock being the *Augen gneiss* of Europe I assume that all the areas of this rock are identical in age, and, in speculating upon the relative positions of the intervening groups, rely upon the correctness of this starting point. . . . . The fact of minor differences would seem to confirm our assumption of their identity in age, just as the paleontologist finds, from the presence of the same fossils, proof of contemporaneity in rocks with dissimilar mineral character. From these facts [the supposed relations of the rocks] it is inferred that the porphyritic gneiss is older than either the Lake or the Montalban gneisses, the last being the newest. . . . . It may as well be said now as at any time, that nothing older than the porphyritic gneiss has yet been discovered. This formation constituted the first dry land in the state." (*l. c.*, pp. 659, 660, 663, 664.)

The equivalency of the New Hampshire formations with others is in part stated as follows : —

"The first two of our groups may be referred to the oldest of these, the Laurentian, without great hesitation. . . . . A porphyritic or *augen* gneiss is eminently characteristic of the fundamental rocks in every part of the world, and hence ours may readily be called Laurentian. . . . . Those who are familiar with the crystallines, as Prof. Dana and Dr. Sterry Hunt, after examining some parts of the Bethlehem group in New Hampshire, say that there is a close resemblance between them and the Laurentian. . . . . I have grouped these rocks, the porphyritic and Bethlehem gneiss, as Laurentian.

"The next division, the Lake gneiss, cannot be so readily assigned. Its affinities are strongly with the Laurentian, but it is not pyroxenic nor porphyritic, nor does it abound in any triclinic feldspar. . . . . In Massachusetts this group carries the *Eozoön*, but that fossil is not confined to the Laurentian. . . . . The Montalban series are certainly not characteristic of the Laurentian. . . . . Dr. Hunt is satisfied that they *overlie* the Huronian or greenstones. Our own observations lead to the view that the typical Montalban rocks *underlie* the same, as recently stated, though the precise relationship is not beyond controversy." (*l. c.*, pp. 668, 669.)

The other formations are in like theoretical manner referred to their supposed places, with the exception of the Helderberg series.

Again, it is said regarding the arrangement of the feldspar in the "Porphyritic gneiss or granite," that

"sometimes the crystals are placed in the rock with their longer axes parallel to each other, and this plane is coincident with that of the strata. On the contrary there is often no arrangement to correspond with the stratification. . . . . It is obvious that one of these rocks must be granite and the other gneiss. In our explorations no distinction has been made between them. The assumption has been that the agencies producing the granite operated with greater intensity, so as to induce a party condition in the mass, and obliterate the stratification without destroying the porphyritic aspect of the rock. If the difference in condition involves radical distinctions in the mode of origin or in the time of the fusion, then there are two formations to be considered instead of one. But in that event the second rock was derived from the first, so that the assignment of both to one group at present will not lead to error in respect to the geographical areas occupied by the porphyritic rock. . . . . Being regarded as granite, no pains were taken to observe lines of stratification in it which doubtless exist. . . . . The determination of the dip of this rock near the wing road station has been a difficult matter. There are jointed planes, with scarcely any inclination that might be taken for strata. At the suggestion of Dr. T. Sterry Hunt, a crystalline arrangement of materials dipping 75° S. 40° E. was decided upon to represent the strata." (Geology of New Hampshire, II. pp. 98, 99, 102, 274.)

In the same work, pages 472, 513, 514, Mr. J. H. Huntington says of the porphyritic gneiss : —

"The fact that rounded fragments of a dark gneiss are found in the porphyritic shows that the porphyritic rock in Fitzwilliam is either intrusive, or that in the process of metamorphism these fragments were not obliterated, and that the dark gneiss — which is very limited, but resembles some varieties of the Bethlehem gneiss — is the older rock."

He further points to the fact that the Concord granite at Fitzwilliam was intrusive. (*l. c.*, p. 513.)

Mr. Huntington also informs us that the "Concord" granite (Montalban gneiss of Hunt) at Granby, Vermont, is distinctly eruptive, being seen in contact with a mica schist, sending tongues into the schist and including fragments of it.

After reading the speculations and conclusions given above, it is somewhat interesting to peruse the following from Prof. Hitchcock's pen : —

"It has been our constant aim to so divorce the facts and theories from each other in the descriptions, that those who hold different general views from our own will not find the observations unwarrantably obscured by individual speculations. . . . . If our interpretation fails in any particular it will be in the

neglect to invoke all the inversions and faults that are required for truthful elucidation." (Geology of New Hampshire, II., pp. 658, 659. See also Am. Jour. Sci., 1877, (3) XIV., pp. 316–321; 1878, XVI., pp. 399–401.)

Since it was evidently the case on the New Hampshire Survey that lithological characters were considered to be all-important in the determination of the age of the crystalline rocks, it seemed desirable to find out what amount of skill had been shown in ascertaining what the character and true names of these rocks really were. A few results of a partial examination, by Dr. Wadsworth, of one of the collections of the New Hampshire Survey, obtained from the State Geologist, may therefore be here introduced for the purpose of throwing light on this question.

As an example of the value of the lithological determinations of this Survey, the typical Exeter syenite may be first taken. The specimen is No. 71 of Hawes's Catalogue, and No. 200 of the "Preliminary Catalogue." This rock is said by Prof. Hitchcock to be lithologically the same as the country-rock of the Merrimac mine at Newburyport,* and the hornblendic granite of Gloucester and Quincy, Mass. All these are regarded as being probably of Laurentian age, and it is recomended that search be made in the Exeter rock for mineral veins, on account of its resemblance to that in which the Merrimac mine is found. The theoretical idea at the base of this piece of advice seems to be, that, even in eruptive rocks, identity of lithological character indicates identity of age, and the probable occurrence of similar metalliferous deposits. (See Geology of New Hampshire, I., p. 27; II., pp. 22, 630; III., Part V. p. 34.) It has by no means been established, as the result of observation, that rocks of the same geological age and mineralogical composition contain the same useful ores; but in the present case it is not necessary to go so far as this, since it can easily be shown that the rocks to which reference is here made have no lithological resemblance to each other.

The Quincy and Gloucester (Cape Ann) hornblendic granites (syenites) were described by Dr. Wadsworth in 1878 (Proc. Bost. Soc. Nat. Hist., XIX., pp. 309–316). They consist of grayish, granitoid, coarsely crystalline aggregates of feldspar, quartz, and hornblende. In some places this granite has a reddish color. This rock was found, on careful examination, at Rockport, to pass, in the same continuous mass, into a micaceous granite, the only difference between the two being that lepidomelane replaced the hornblende. The feldspar proved to be mainly orthoclase. The country-rock of the Merrimac mine, on the other hand, is a dark-

* The real location of the Merrimac mine is, however, in Newbury, not Newburyport.

greenish micaceous and hornblendic schist and gneiss, not having lithologically a single character of the Quincy or Cape Ann granites or syenites.

The specimen of "Exeter syenite" obtained from Prof. Hitchcock, and now in the lithological collection at the Museum of Comparative Zoölogy, is unlike either of the preceding rocks. Macroscopically it appears to be composed of feldspar and biotite, a large proportion of the former appearing as well-striated plagioclase. From its resemblance to rocks of similar character occurring in Maine, it appeared likely that it belonged rather to the basalts than to the granites; in other words, that it was a basic instead of an acidic rock. Microscopic examination of a thin section showed, in fact, that the rock is composed of plagioclase, a little orthoclase, augite, biotite, magnetite, apatite, and some quartz. The augite is seen in places to have suffered alteration and to be partly changed to biotite, a common occurrence, rendering it probable that all the biotite is of secondary origin. The quartz is in small amounts, and occupies the angular interspaces usually filled by the base in such rocks when unaltered; it is therefore probable that it has either replaced the glass in the process of alteration, or was itself residual silica after the other minerals had crystallized out. The plagioclase proves, as determined by the method of Descloizeaux, to be labradorite. This rock, therefore, is a gabbro, or a coarsely crystallized diabase, and belongs rather to the so-called Norian rocks (basaltic) than to the granites. (See M. E. Wadsworth in Proc. Bost. Soc. Nat. Hist., 1877, XIX., pp. 217–238; Bull. Mus. Comp. Zoöl., 1879, V., pp. 275–287.)

We have here, therefore, three rocks, almost as different from each other as it is possible for rocks to be, placed together as alike; and, on this presumed analogy, practical advice in regard to exploration for mining purposes is based.

Another instance which may be cited as illustrative of the value of the lithological determinations of the New Hampshire Survey is that of No. 71 of the Preliminary Catalogue, there called hornblendite, and No. 221 of Hawes's Catalogue, where it is designated as hornblende schist. The locality is Piermont, N. H., and the region where this rock occurs is described as being made up of alternating bands of whetstone slate (mica schist) and hornblende (hornblende schist). Prof. Hitchcock states that

"there are five bands of hornblende schist and five of whetstone slate. . . . . I am inclined to carry out the suggestion of a previous page, to the effect that much of this hornblende should be regarded as Huronian. In agreement with this notion, it would form hummocks underlying the mica schists, probably

Annual Reports: 1869-1872.

1st *Annual Report*, 1869.

Gneissic, Granitic, or White Mountain Series.

Quebec Group.
- Staurolite Schists.
- Lower (mostly green) Schists
- Copper Belt.
- Clay Slate.
- Auriferous Conglomerate.

Upper Schists.

2d *Annual Report*, 1870.

Eozoic.
- White Mountain or Gneissic Series.
  - Normal Gneiss.
  - Ferruginous Gneiss
  - Granitic Gneiss.
  - Feldspathic Mica Schist.
  - Andalusite Gneiss.
  - Chiastolite Slates.
  - Granite.
  - Syenite.
  - Porphyritic Granite.
  - Quartzite.
  - Limestones.
  - Soapstones.

Laurentian (?) Exeter Syenites.
Porphyritic Granite.
Common Granite.
Lower Silurian
- Merrimac Group.
- Quebec Group.

Coös Group.
Calciferous Mica Schist.
Clay Slates.

3d *Annual Report*, 1871.

Laurentian (?)
- Porphyritic Gneiss
- Bethlehem Gneiss.
- Gneiss.
- White Mountain or Andalusite Gneiss.
- Common Granite.
- Trachytic Granite.
- Brecciated Granite.
- Norian.

Clay Slate and Quartzites.
Coös Group.

4th *Annual Report*, 1872.

Division 1.

Huronian.
- Hydro-mica and Talcose Schists,
- Conglomerates, and Quartzites.

Cambrian.
- Auriferous Clay Slates.
- Coös Group.
  - Quartzites, Staurolite Schists,
  - Mica and Argillaceous Schists,
  - Calciferous Mica Schist,
  - Decomposing Slates, Dikes.

Helderberg.

Division 2.

Laurentian.
- Porphyritic Gneiss and Granite.
- Bethlehem and Berlin Gneiss.
- White Mountain or Andalusite Gneiss.
- Franconia Breccia.

Norian. Pemigewasset Basin.
- Common Granite.
- Spotted Granite.
- Four Series of Compact Feldspar.
- Green Granite and Syenite.

Division 3.

Laurentian
- Porphyritic Gneiss and
- Granite.

Granitic Gneiss.

White Mountain Series.
- Andalusite Gneiss, Ordinary and
- Imperfect Gneiss, the Concord and Fitzwilliam Granite,
- Soapstone and Limestone.

Quartzite.
Mica Schist.
Andalusite Slates of the Coös Group.

Proc. Am. Assoc. Adv. Sci., 1872, XXI. 134, 135, 150.

I. Eozoic.
- 1. Laurentian.
  - *a*. Porphyritic Gneiss.
  - *b*. White Mountain Series, or Andalusite Gneiss.
  - *c*. Bethlehem, or Talcose Gneiss.
  - *d*. Gneiss of Lake Winnipiseogee Basin.
  - *e*. Gneiss on both flanks of the Porphyritic variety in the south part of the State, carrying the Concord and Fitzwilliam Granite, and is probably the Beryl-bearing Series.
  - *f*. Range of Gneiss between Whitefield and Milan, considerably hornblendic.
- 2. Norian.
  - *a*. Common Granite.
  - *b*. Trachytic Granite.
  - *c*. Ossipyte.
  - *d*. Compact Labradorite Felsite.
  - *e*. Dark compact Orthoclase Felsite.
  - *f*. Red compact and Crystalline Orthoclase Felsite.
- 3. Exeter Syenites.
- 4. Huronian
  - The Talcose Schist Series.
- 5. Older Cambrian.
  - Coös Group.
  - Merrimac Group, and probably Calciferous Mica Schist of the Vermont Survey.

II. Paleozoic.
- Helderberg Limestone.
- Clay Slates.

3.

. Bost. Soc. Nat. His., 1873,

XV. 304–309.

A Porphyritic Gneiss.
B. Bethlehem Gneiss.
C. White Mountain or Andalusite Gneiss.

A. Common Granite of the White Mountains
B. Spotted Granite.
C. Ossipyte
D. Dark compact Labradorite.
E. Dark compact Orthoclase.
F. Red compact Orthoclase.
G Reddish compact Orthoclase
H. Syenites of Exeter and Tripyramid.

Talcose and Auriferous Conglomerates.
Green Schists.
Whitish Schists
Feldspar and Talc.

A. Mica Schists of Rockingham County.
B. Merrimac Group.
C. Coös Group.
D. Clay Slates.
E. Green Granite.
F. Mt. Mote Conglomerates

1. Helderberg Limestone.
2. Clay Slates.

Am. Assoc. Adv. Sci., 1873,

XXII. 120–131.

Winnipiseogee Lake.

Porphyritic Gneiss or Granite.
Winnipiseogee Lake Gneiss Formation.
White Mountain Series.

Eruptive Granites of the Ossipee Mountains.
Felsites or Compact Feldspars.

ptive Syenite.
Schist.

Geology of New Hampshire, 1874,

I. 506–539.

Eozoic.
- Laurentian. — Porphyritic Gneiss.
- Atlantic. — Bethlehem. Lake Gneiss. Montalban. Franconia Breccia Group.
- Labrador. — Conway Granite. Albany Granite. Chocorua Granite. Fine Sedimentary Deposits. Eruptive Syenite.
- Huronian. — Copper and Iron Beds. Dolomite, Soapstone, and Serpentine with Siliceous Schist. Conglomerate.

Mica Schist Period. — Rockingham Mica Schist. Merrimac Group. Cambrian Auriferous Clay Slates. Coös Group.

Helderberg Period.

Walling's Atlas of New Hampshire,

1877.

Eozoic.
- Laurentian. — Porphyritic Gneiss.
- Atlantic. — Bethlehem Group. Lake Winnipiseogee Gneiss. Montalban or White Mountain Series. Franconia Breccia.
- Labrador or Pemigewasset. — Conway Granite. Albany Granite. Chocorua Granite. Ossipyte. Compact Feldspar. Exeter Syenites.
- Huronian. — Lisbon Gronp. Lyman Group. Auriferous Conglomerate.

Paleozoic.
- Cambrian. — Rockingham Schists. Calciferous Mica Schists. Coös Group. Clay Slates. Mt. Mote Conglomerate.
- Silurian. — Helderberg Limestones. Slates, Conglomerates, &c.

Geology of New Hampshire, 1877,

II. 674, 675.

I. *Stratified Groups.*

Eozoic.
- Laurentian. — Porphyritic Gneiss. Bethlehem Ordinary Gneiss. Bethlehem Fine-Grained Gneiss. Lake Winnipiseogee Gneiss.
- Montalban. — Gneiss and Feldspathic Mica Schists. Concord Granite. Ferruginous Schists. Fibrolite Schists. Franconia Breccia.

Labrador.

Lower Huronian.

Upper Huronian. — Hornblende Schist. Swift Water Series. Lisbon Group. Lyman Group. Auriferous Conglomerate.

Paleozoic (?)
- Ferruginous Slates. Merrimac Group. Rockingham Mica Schist. Kearsarge Andalusite Group.

Paleozoic.
- Cambrian Slates.
- Coös Group — Quartzite. Mica Schist. Staurolite Slate.
- Calciferous Mica Schist.
- Lower Helderberg.

II. *Eruptive Masses.*

Granitic.
- Conway Granite.
- Albany Granite.
- Chocorua Series.
- Granite cutting Coös Group.
- Granite not otherwise assigned.
- Syenite of Mt. Gunstock, etc.
- Exeter Syenite and Diorite.

Augitic. Feldspathic.
- Labradorite Diorite.
- Porphyry.
- Pequawket Breccia.
- Trachyte.

- Diorite.
- Diabase.

uncomformably. . . . . This theory will explain the occurrence of the whetstone rock in limited outlying patches. . . . . Were it interstratified with the hornblende, it should descend into the earth at the same angle to indefinite depths." (Geol. of New Hampshire, II., p. 379.)

On examination, however, of this so-called hornblende schist, both in the hand specimen and microscopic slide, we find it to be a well-marked diabase, a rock that so far has always, when carefully studied by competent observers, been considered to be eruptive.

No. 121, called "granite from bed" in the Preliminary Catalogue, ("feldspar from bed," Hawes's Catalogue) is the same as the sandstone No. 117 (Prelim. Cat.), both being masses of feldspar with a little quartz. No. 86 of the Preliminary Catalogue, called "serpentine, very impure," from Norwich, Vt., is regarded as Huronian. (Geol. of New Hampshire, II., pp. 360, 361.) This rock is a mixture of quartz and hornblende, with considerable epidote, but we cannot find the slightest sign of serpentine about it, either macroscopically or microscopically.

We might go much further in illustrating the character of the lithological determinations of the New Hampshire Survey, and the probable value of these as forming a basis for a geological classification, but we forbear.

The criticisms here made depend of course on the authenticity of the specimens used. On this point we quote Prof. Hitchcock: —

"Pains have been taken to have all the specimens exactly alike, so that those who obtain duplicate collections, by purchase or otherwise, may be sure that Mr. Hawes's accurate descriptions in the chapter on Lithology are applicable to their set." (Geol. New Hampshire, Part IV. p. 261.)

Dr. Hawes, however, appears to have had his doubts with regard to the uniform character of the various collections prepared by the New Hampshire Survey, for he expressly states that it is only for the collections preserved in the Peabody Museum at Yale College that he is to be held responsible (*l. c.*, p. 255).*

Further remarks on the methods of work of the New Hampshire Survey, and the character of the classification established on a purely lithological basis, will be found in the second part of this memoir. At present it will be sufficient to present in a tabular form (Table B.) the different results arrived at from year to year, as displayed in the re-

* It is a fact, as shown by actual examination, that, in various collections obtained from Prof. Hitchcock by different parties, specimens bearing the same number, and purporting to be from the same locality, are — in some cases, at least — quite different from each other.

ports of the State Geologist, published while the work was going on. The scheme here presented is as complete as it has been found possible to make it. So numerous are the contradictions in the published statements made from year to year, that only an intimate personal acquaintance with the geology of New Hampshire would make it possible to prepare a connected scheme of the subdivisions of the geological formations of that State, as from time to time set forth in Professor Hitchcock's reports.

EASTERN MASSACHUSETTS.

The first paper of which the writers are aware, relating to the lithology of the vicinity of Boston, is that of Mr. S. Godon, entitled, "Mineralogical Observations, made in the Environs of Boston, in the Years 1807 and 1808." (Mem. Am. Acad., 1809, (1) III., pp. 127–154, with a Table; Ann. Mus. Hist. Nat., 1810, XV., pp. 455–472.) From this paper it appears that Mr. Godon united under the name *amphiboloid* all the rocks in this region which he supposed to be composed of amphibole and feldspar, when the former mineral predominated. When the latter was more abundant than the hornblende, the rock was called *felsparoid*. It seems from his descriptions that he included under the term amphiboloid part of the granitic and all of the basaltic rocks (diabase, diorite, and melaphyr) except the amygdaloid and possibly some diabase.

The amphiboloid was divided into the following series: Common, Granitic, Trappine, Porphyritic, Epidotic, Quartzose, Micaceous, and Talcous Amphiboloid. The presence of epidote in small veins both in the amphiboloid and felsparoid was noticed and described.

The felsparoid included the hornblendic granite both north and south of Boston, and probably some of the coarser diabases. The felsparoid was said to be often micaceous, and in general to present no distinct stratification. Mr. Godon also remarks, that "the transition of felsparoid to petrosilex and porphyritic petrosilex is frequently observed in the compass of the present observations." He cites, as localities where the transition can be observed, Milton, Blue Hills, and Malden.

The felsparoid was divided as follows: Common, Quartzose, Epidotic, and Granitic Felsparoid.

The felsite he classes under the head of Petrosilex, but thinks that, instead of petrosilex being a simple mineral, as it was then generally regarded, possibly it might be compound in its nature.

He makes the following divisions of the petrosilex: —

"Simple Petrosilex { Flinty Petrosilex. / Sonorous " / Jasper " / Novacular "

"Porphyritic Petrosilex."

The name *simple petrosilex* seems to have been confined to the more apparently homogeneous felsites, while the term *porphyritic petrosilex* was given to those rocks supposed to have a base of simple petrosilex, or of felsparoid which held enclosed porphyritic crystals. The simple petrosilex was thought to pass into wacke and felsparoid.

The common argillite of the country was denominated *argilloid*, and it was supposed to pass into petrosilex. He separated it into the following divisions: Common and Novacular Argilloid. An imperfect chemical analysis was made of some of the argilloid that resembled the *sonorous petrosilex*.

The conglomerate of the district was called *wacke*. Mr. Godon says of it: —

"How much attention soever I have paid to the examination of this rock *in situ*, I have never observed in it any distinct stratification. It commonly unites with the rocks previously described, and with amygdaloid, often by an insensible transition. I possess specimens, which, on pieces of four inches square each, present its different passages to felsparoid, amphiboloid, simple and porphyritic petrosilex, argilloid, &c."

His explanation of its origin is interesting, not only as illustrating some of the views of that time, but also from its general resemblance to the conclusions and statements in some more recent articles on the geology of Eastern Massachusetts.

"If permitted to venture an opinion on the mode of its formation, we may suppose, that, as we find in it specimens of almost all the rocks, which predominate in the country, it originated from a motion, which disturbed and divided the vast deposits of felspathic, porphyritic, petrosiliceous, &c. rocks, while they were passing from the state of fluidity to that of solidity. This motion ought to be supposed as having taken place before the complete solidification of these rocks; since the compactness of the wacke indicates that its

elements were in a state of softness, which permitted the union of these heterogeneous bodies to form a solid mass. Moreover this aggregation cannot be supposed to have been formed after the last cast of the primordial deposit, because the rents, which took place in its mass, have been filled by veins or rather strata of amphiboloid and felsparoid . . . . which demonstrates, that these minerals were still depositing themselves, at a period later than the formation of the wacke."

The amygdaloidal basalt (melaphyr) was called amygdaloid, and regarded as made up of nodules cemented by an apparently homogeneous reddish-brown or greenish substance. It is said that

"sometimes it occurs with a schistous texture, and even emits an argillaceous smell, when breathed on. This rock is analogous to the toadstone of the English."

In Godon's work is seen the same theoretical belief in the passage of one rock into another which has since his time played so important a factor in the geological papers in this region, all resting, however, on theory and imperfect observation.

Next in order followed Mr. William Maclure's paper, entitled "Observations on the Geology of the United States, explanatory of a Geological Map," (Trans. Am. Phil. Soc., 1809, VI., pp. 411–428,) which was followed by an enlarged paper on the same subject in 1817. (Ibid., 1818, (2) I., pp. 1–91.) The latter paper was also published as an independent work in 1817. Maclure, following Werner, arranged all rocks in four classes: Primitive, Transition, Floetz or Secondary, and Alluvial Rocks.

Dr. Hunt in his History of the Azoic Rocks (Second Geological Survey of Pennsylvania, 1878, E., Part I. pp. 23, 24) fell into the error of making Maclure's classes of rocks five in number. This was done by Dr. Hunt's placing the "Old Red Sandstone" as a distinct class, although Mr. Maclure regarded it as belonging to the Floetz or Secondary class, being one of the twelve formations into which that class was divided. Dr. Hunt's mistake probably arose from the fact that the "Old Red Sandstone" (Mesozoic) of Maclure was colored distinctively on the map, which was the case with all the *classes*, but not with the *other formations*. This rock was furthermore placed at the base of the Secondary, and regarded as making a passage from the Transition to the Secondary classes.

The rocks in the vicinity of Boston were placed by Maclure in the Primitive and Transition classes. The Transition corresponded generally with the conglomerate in this region, and it was directly connected with the Rhode Island Coal Basin, then regarded as Transition.

Prof. Parker Cleaveland's "Elementary Treatise on Mineralogy and Geology" followed Maclure and Godon in the first edition (1816), with the addition of the Messrs. Dana's observations in the second edition (1822), and therefore no reference need be made to Cleaveland's views.

In 1818 was published the "Outlines of the Mineralogy and Geology of Boston and its Vicinity, with a Geological Map," (Mem. Am. Acad., 1818, (1) IV., pp. 129–223,) by the brothers J. F. and S. L. Dana. This was, and is, a very important contribution to the mineralogy and lithology of the region, although it is weak in its petrology and geology, as would naturally be expected from the authors' line of research. This paper probably contains the best account of the mineralogy of the region which has yet been written. The general distribution of the rocks was shown on a map, but this is very imperfect.

The argillite was regarded as the oldest rock known in the region. (*l. c.*, p. 199.) The trappean rocks were called greenstone, greenstone porphyry, and green porphyry; the last two being regarded as varieties of greenstone. Attention was especially called to the globular disintegration of the greenstone, so well marked at some localities in this vicinity. (Proc. Bost. Soc. Nat. Hist., 1877, XIX., pp. 217–237.) They state that the greenstone has not been observed stratified, and that it overlies the argillite. It is also said to occur in large beds in the latter, while it is further claimed that it passes into syenite in places.

The felsite of the district was divided into two classes: petrosilex and porphyry. The petrosilex was regarded as a mineral, and the term applied only to the compact felsite, e. g. the so-called Saugus jasper. The banding of and irregular colored patches in the felsite were regarded simply as variations in the coloring of the mineral, and not stratification. This to a certain extent agrees with the results of modern investigation. Porphyry was the term applied to the felsite, whose base was held to be petrosilex, in which minerals were porphyritically embedded, especially quartz and feldspar. The feldspar was said generally to be in "rectangular crystalline grains, and the quartz in small rounded nodules." (*l. c.*, p. 204.) They further state that the "porphyry is unstratified in this vicinity, and is intimately connected with Sienite and Petrosilex, into both of which it passes." (*l. c.*, p. 205.)

The hornblendic and micaceous granites were classed as "sienite." The rock was regarded as principally a compound of quartz, feldspar, and hornblende, but it was said that "mica sometimes forms a large proportion of the mass; and hills of Sienite, of a fine structure, containing mica in quantity nearly equal to the other ingredients, prevail

for a great extent, particularly at Danvers." It was also stated that "Sienite has not been observed stratified in this vicinity." (*l. c.*, p. 207.)

The amygdaloidal basalt or melaphyr was called Amygdaloid, and regarded as a rock having a homogeneous base. This base was supposed to have been originally cellular, and the cells afterwards filled with the minerals, "Petrosilex, Quartz, Feldspar, Epidote and Carbonate of Lime," forming the amygdules. The base was denominated "Wacke," which in common with petrosilex and basalt was held to be a simple mineral. The amygdaloid was said to be destitute of stratification, but to present sometimes an imperfect slaty structure. This rock was said to repose on, and to be associated with, the greywacke (conglomerate) of the vicinity.

The conglomerate so common in the vicinity of Boston was called greywacke, and said to be "composed of nodules of Petrosilex, Quartz, Argillite, Feldspar, Porphyry, and Sienite; some of these nodules approach, in magnitude, to rolled masses, and from these we find a gradual gradation to grains of sand." (*l. c.*, p. 210.) No stratification was observed in the greywacke and greenstone; argillite and amygdaloid are said to form beds in the greywacke. The amygdaloid was said to be intimately connected with the greywacke.

In 1818 there was also published Dr. Amos Eaton's "Index to the Geology of the Northern States, with a Transverse Section from Catskill Mountain to the Atlantic."

Like Maclure and the brothers Dana he follows the Wernerian system in a somewhat modified form, dividing the rocks into five classes: Primitive, Transition, Secondary, Superincumbent, and Alluvial.

He explains the presence of granite boulders in the vicinity of Boston and elsewhere as follows: —

"The sienite stratum was formerly much thicker than at present. This aggregate has been long known to be strongly disposed to disintegration. It has dissolved and set loose the enduring granite, which now lies in loose blocks, with fragments of sienite attached to them, on the surface of the alluvial deposites."

This gives us the germ of the theory of the local origin of boulders by disintegration. Beyond this, the finding of a syenite boulder in front of the State House in Boston, and of fragments of argillaceous and graywacke slate near the same city, appears to be all that he knew of the geology of this district.

In the second edition, under date of 1820, argillite was thought to

exist in the vicinity under the "deep alluvion" on account of the "large patches and fragments" which he found there (*l. c.*, p. 168). In his section Dr. Eaton represents hornblende rock as extending from Framingham to Boston, and dipping towards the sea at a gentle angle. Underlying this blanket of hornblende rock was gneiss, and then granite. Most of his information regarding the geology of Boston seems to have been taken from the Messrs. Dana's Outlines, referred to in the preceding pages.

According to the Rev. Elias Cornelius, the rocks at the eastern portion of the peninsula on which the city of Salem was built "are either a pure granite, or that variety of it called sienite, the hornblende of which is diffused in different proportions, from a few specks scarcely discernible, to very considerable quantities." (Amer. Jour. Sci., 1821, (1) III., p. 232.)

Dr. Thomas Cooper later remarked that "no person accustomed to volcanic specimens can look at the porphyries from the neighborhood of Boston, in my possession, and doubt of their volcanic origin." (Ibid., 1822, (1) IV., p. 239.)

In his Sketch of the Geology, &c. of the Connecticut, Prof. Edward Hitchcock states that epidotic and syenitic greenstones belonging to the Transition exist in the vicinity of Boston, and that dikes of basaltiform greenstone occur in the syenitic granite in the same region. (Ibid., 1824, (1) VII., p. 30.)

In a section given by Dr. Amos Eaton in his "Geological and Agricultural Survey of the District adjoining the Erie Canal," beginning at Boston and passing through Waltham, Weston, Sudbury, and Framingham, the country-rock is represented as being "hornblende rock including all its varieties." This rock is given as extending from Boston to midway between Framingham and Shrewsbury, and is figured as having a steep easterly dip. A patch of argillite is represented as horizontally underlying Harvard College and resting on the upturned edges of the "hornblende rock."

In the description of a section made by Prof. Edward Hitchcock, and placed at the end of the above-quoted work, the rocks in the vicinity of Boston are said to be syenite, argillite passing into greenstone slate, pudding-stone, amygdaloid, transition argillite, greenstone, and petrosiliceous porphyry. Veins of dark compact greenstone are said not to be uncommon in syenite and syenitic granite, in the vicinity of Boston. He cites Dr. J. W. Webster as authority for the statement "that the only rock ever found *in situ* in Boston" is syenite. A peculiarity of

Prof. Hitchcock's section is, that all the formations lying between Boston and a point some seventy miles west are represented as extending perpendicularly downwards.

Later, Prof. John W. Webster published his "Remarks on the Geology of Boston and Vicinity." (The Boston Journal of Philosophy and the Arts, 1824–25, II., pp. 277–292; 1825–26, III., pp. 486–489.) He states that the Boston peninsula exhibits no rock in place except at one locality. This was a light gray clay slate (argillite) found by digging to a considerable depth below the surface. The syenite seen, which had led to the belief that the rock of the peninsula was syenite, had been found to be a boulder. Winter Hill of Charlestown (now in Somerville) was said to be composed of clay slate passing on the north into hornblende slate. The dip was towards the north, at an angle of from 15° to 20°. These rocks contain "beds and veins of greenstone." The lowest rock on Prospect Hill, near Winter Hill, was regarded as a greenish compact feldspar,* in places strongly resembling some varieties of limestone. This rock passed into clay slate and dipped "to the south, inclining a little to the west, under an angle varying from 20° to 50°." This was overlain by trap, which it was thought once formed an extensive bed covering the slate. The Granite Street diabase of Prospect Hill was described and called a "sienitic greenstone." Likewise the diabase of the Powder-House, Somerville, and of Medford, is mentioned, and the boulder-like disintegration pointed out. The occurrence of slate north of the Powder-House was noted, together with trap overlying the slate or interposed between the strata.

The Roxbury conglomerate was described at some length, and said to pass "into coarse grau wacké, fine grained grau wacké, and grau wacké slate which becomes at last distinct clay slate." The components of the conglomerate enumerated were hornstone, quartz, compact feldspar, flinty slate passing to Lydian stone, porphyry, granite, clay slate, novaculite, serpentine, and nephrite. The occurrence of "trap veins or dikes" in the conglomerate was noticed. The conglomerate was said to pass into amygdaloid, the latter being the overlying rock. Another transition observed was in crossing the conglomerate of Dorchester, which was seen to acquire "a greater degree of compactness and uniformity of composition until within about three miles of the Blue Hills, where it passes into compact feldspar, and this last into hornstone." The Blue Hills were said to be composed principally of a "peculiar porphyry resembling some of the trachytes." This rock overlaid the sye-

* This is the indurated argillite of that vicinity.

nite. The clay slate was thought to underlie all the other rocks to form the islands in Boston Harbor. The presence of slate in Quincy was noticed. The rock of Marblehead was designated as syenite. The Malden felsite was called porphyry, and that of Saugus a "bright red jasper." Of Nahant he remarks that the slate "has undergone a striking change from the presence of the huge veins of trap with which it is traversed in every direction." Prof. Webster previously had published a short account of the limestone of Stoneham, which he thought was probably in a bed. (Bost. Jour. Phil. and Arts, 1823–24, I., pp. 95, 96.)

In the Report on the Geology, Mineralogy, Botany, and Zoölogy of Massachusetts, by Prof. Edward Hitchcock, published in 1833, considerable attention was given to the geology of Eastern Massachusetts. (See also Am. Jour. Sci., 1833, (1) XXII., pp. 1–70.)

The conglomerate of Brighton and elsewhere was denominated graywacke, said to be stratified, and "sometimes beautifully amygdaloidal." The amygdaloidal portion was regarded as "rather *wacke* than graywacke." The wacke "often forms the cement of graywacke." The localities of the amygdaloid were given as Brighton, Brookline, Newton, Needham, Hingham, and Saugus. (*l. c.*, pp. 33, 34.) It can be readily seen from reading President Hitchcock's report that he holds that all the amygdaloidal melaphyr above mentioned passes into the conglomerate, the former being only a variety of the latter. The amygdules were according to him formed by fusion, except in some cases where they were formed by infiltration. (*l. c.*, pp. 248–262.) The argillite of Nahant he regards as part of the graywacke formation belonging to the Transition. The argillite there he calls flinty slate, and appears to hold that the induration was caused by the trap veins passing through it. He also remarks: —

"The slaty structure is rarely lost, except at the junction of the greenstone and slate, where the two rocks are so intimately blended, that it is not easy to fix upon the spot where either of them commences. This corresponds with the opinion of Dr. Maculloch, that nothing but the requisite degree of heat is necessary to convert argillaceous slate into greenstone." (*l. c.*, p. 265.)

The argillite (argillaceous slate of Hitchcock) in the vicinity of Boston was described with the graywacke formation, although President Hitchcock was inclined to make it older.

The limestone of Stoneham, Newbury, and Chelmsford, he held to be in beds, modified by the action of granite and syenite, which had obliterated the lines of stratification. (*l. c.*, pp. 308–313.)

The unstratified rocks were assigned an igneous origin without exception. They were regarded as having been formed during diverse ages, the author holding that

"their intrusion among the stratified rocks affords an important clue for determining their relative ages. It is obvious, however, that the intrusion of the former among the strata of the latter, only proves that the unstratified rock was formed posterior to the stratified one."

While we believe that the above quotation from President Hitchcock's work is essentially sound in its views, it will be seen in the sequel that considerable work has been done in this vicinity from a diametrically opposite point of view.

President Hitchcock further held that all these rocks were

"merely varieties of the same melted mixture, whose peculiarities resulted from the modes in which they were cooled, and crystallized, and intruded among the stratified rocks. . . . . On this supposition we are no longer surprised to find it impossible to draw any definite line between the different varieties, nor to find them all united in the same mountain mass."

He inclined to the opinion, that all the unstratified rocks of Massachusetts belonged to a single family, but concluded to treat of them all under four divisions, viz. greenstone, porphyry, syenite, and granite. The order of production according to him, beginning with the lowest, is as follows: granite, syenite, porphyry, and greenstone. He further states: —

"Porphyry, however, passes by insensible gradations into sienite; but the change commonly takes place in a vertical and not in a horizontal direction." (*l. c.*, pp. 402–404.)

The greenstone was regarded as a mixture of hornblende and feldspar, although some at Nahant was thought to contain augite. This rock was said to be mixed with syenite in every conceivable mode, and to pass into it and into granite. The former rock was in general the younger, although cases were observed in which the latter held fragments of the greenstone. A special case is cited, a little west of Marblehead village, and explained as follows: —

"They certainly appear as if the greenstone had been partially melted down in the granite; though the heat was not great enough to complete the fusion. Or rather, may it not be probable, that the perfect fusion of the rock out of which these unstratified ones were produced, gave rise to the granite; while those portions that were not so entirely fused as to admit of entirely new and perfect combinations and crystallizations, might have formed those portions of the rock which I call greenstone."

It appears from his remarks in connection with this, that in his opinion a more or less perfect fusion of the same materials may have been the principal cause of the production of greenstone, syenite, porphyry, and granite from them.

The unstratified rocks were said to "occur in three modes: first, as protruding irregular masses; secondly, as overlying masses; and thirdly, as veins." The greenstone he held to be principally of the first class, but considered that it also occurred in veins. In regard to these points he thus expresses himself: —

"Wherever I have seen this rock associated with the graywacke and argillaceous slate in the eastern part of the State, it either occupies veins, or protrudes itself in some other form, among, or between, the strata. . . . . It has there also the appearance of being regularly interstratified with the slate. But I am satisfied that this is a deception; that is to say, these supposed beds are connected with some unstratified masses. Yet I think it extremely probable that some of the greenstone in the vicinity of Boston has resulted from the fusion of clay slate; and perhaps it is possible that a particular portion of the slate might be converted into greenstone, while that around it might remain but little changed; and in such a case, the altered rock might at the surface appear interstratified with the other."

On Nahant the presence of two sets of trap dikes was noticed, and it was held that the slate was in the form of a clay at the time of the intrusion of the greenstone which altered it. The apparent distinct stratification (jointing?) of some greenstone on this promontory was regarded as the result of a concretionary structure. Part of the veins (dikes) were said to run parallel with the strata, and it was thought that they would be regarded by some geologists as being regularly interstratified with the slate. President Hitchcock gives the following as the reasons why he holds the greenstone to be of igneous origin: —

1. "The resemblance in external characters between some varieties of our greenstone and the products of existing volcanoes."
2. "The columnar structure of greenstone."
3. "The irregular manner in which greenstone is intruded among stratified rocks."
4. "The Mechanical effects of Greenstone upon the Stratified Rocks."
5. "The Chemical effects of Greenstone upon the Stratified Rocks."

These views were illustrated by examples. (*l. c.*, pp. 404–442.)

The porphyry is divided into four classes: 1. Compact Feldspar: 2. Antique Porphyry; 3. "Porphyry with a base of compact Feldspar and two or more minerals embedded"; 4. Brecciated Porphyry. The last he describes as being

"composed of angular fragments of porphyry and compact feldspar, re-united by a paste of the same materials, which is itself also porphyritic. Hence it appears that there must have been an original formation of these rocks (compact feldspar and porphyry) which was subsequently broken up, either by the mechanical agency of water, or the mechanico-chemical agency of heat, redissolving and mingling the materials."

Of the geological position he remarks: —

"Am I asked whether the porphyry of Massachusetts belongs to the Primitive, Transition, or Secondary Class? I reply that it belongs to none of them, but is a member of a series of rocks consisting of granite, sienite, porphyry, and greenstone, which have been protruded through or among the stratified rocks, subsequent to their deposition. . . . . The mere existence of these rocks, therefore, among those of any particular stratified class, does not prove that they were produced at the same epoch; it rather proves that the unstratified rock was of subsequent production. . . . . I have never met with an instance in which this porphyry was exhibited in juxtaposition with any stratified rock: except as already remarked, the compact feldspar succeeds to the graywacke as an older rock and gradually passes into porphyry. This porphyry, however, is associated, both on the north and south of Boston, with sienite; and in all cases, so far as I have observed, *the porphyry lies above the sienite*, and there is a gradual transition between the two rocks."

The compact feldspar was considered to have been derived from the melting of common feldspar or albite, in connection with other minerals. He remarks as follows in regard to this compact feldspar: —

"That it does result from this change in common feldspar, I can hardly doubt, when I often see specimens that have not entirely lost their foliated structure, being intermediate between the two minerals. . . . . It is not uncommon to meet with specimens of porphyry that exhibit traces of an originally slaty structure in all or a part of the materials composing it. This clearly points us to a slaty rock as the source from which porphyry was derived. And sometimes fragments of this rock, along with fragments of compact feldspar, flinty slate, &c. are scattered through the mass as if partly melted down; very much as fragments appear in the slag of a furnace. They seem to be all but incorporated with the paste, and the whole mass presents an appearance of a more perfect chemical union than any rock resulting from aqueous agency ever exhibits, unless it be entirely crystalline. . . . . The gradual passage of this rock into sienite, without any apparent change of ingredients, seems to indicate that the peculiarities of porphyry did not result chiefly from the nature of the materials employed in its production." (*l. c.*, pp. 442–451.)

Under the term syenite President Hitchcock included "all the varieties of rock, between greenstone and porphyry on one side, and common granite on the other, into whose composition hornblende enters." His

varieties of syenite were six, of which only the first five occur in the district under discussion here. It would seem that he included under the name syenite many diabases as well as hornblendic granites. The division of the rock into parallel portions observed in one locality on Cape Ann he regards as pseudo-stratification (concretionary structure), and not real stratification. The syenite was said to pass by insensible gradations into granite on one side, and into greenstone or porphyry on the other, the author remarking as follows: —

"Or when these rocks are wanting, some of the stratified rocks, such as hornblende slate, graywacke, or new red sandstone repose upon it. .. . . In all cases where this rock occurs, we find it between the oldest granite and greenstone, or the earlier stratified rocks. Hence I infer that a portion of the materials of which granite is composed, under certain circumstances were converted into sienite, and that these circumstances existed generally in that portion of the melted granite nearest the newer stratified rocks. Or if we suppose it erupted at a different epoch from the granite, certain causes always forced it upwards between the granite and the newer rocks. Or if we suppose it to have resulted from the melting down of the stratified rocks, then perhaps their more or less perfect fusion produced the difference which we find between granite and sienite."

The syenite is said to penetrate "sienite of a different variety, or greenstone." President Hitchcock thought that the evidence in favor of its igneous origin was not strong, yet he held that view. (*l. c.*, pp. 451–465.) A second and revised edition of this report was published in 1835, but his views remained essentially unchanged.

In 1838 was published President Hitchcock's "Report on a Reexamination of the Economical Geology of Massachusetts." In this the existence of the Lynnfield serpentine was pointed out (pp. 137, 138).

President Hitchcock's Final Report was published in 1841, and in it certain changes were made. The graywacke was subdivided into the Coal Measures, Old Red Sandstone, and Graywacke. The last comprised the conglomerates about Boston Harbor and in some other localities (*l. c.*, p. 534). The argillite in the vicinity of Boston was still included in it, although lower in the series. Under the head of "Metamorphic Slates" were classed among other formations "Aggregates of Porphyry," "Varioloid Wacke," and the "Flinty Slate of Nahant." Of the first he says: —

"The best example . . . ., perhaps, is in Hingham, a little west of the village; and in Cohasset, at the head of Nantasket Beach. At the latter place is a coarse breccia, or conglomerate, which is chiefly made up of fragments of porphyry reunited by a cement of the same materials, and is sometimes almost

reconverted into compact porphyry. . . . . At the head of Nantasket Beach is another metamorphic rock, lying contiguous to the breccia just mentioned. . . . . I incline to the opinion that it was originally a hard slate, like that on Nahant, and the Brewster Islands, which has been very much changed and filled up with veins of epidote, by the action of heat. Some of it appears as if converted into a sort of compact feldspar." (*l. c.*, pp. 547, 548.)

The latter rock he described in the Report for 1833 (p. 255) as consisting of "fragments of gray and yellowish green compact feldspar, united by an unknown dark-colored cement."

The "varioloid wacke" is the amygdaloid of most writers on the geology of Eastern Massachusetts, and, as in 1833, President Hitchcock holds that it passes into and "is only a metamorphic variety of the graywacke formation." (Final Report, 1841, pp. 548, 549.) In this Report he held that "the different unstratified rocks appear to be the result of volcanic agency exerted at different periods under different circumstances," and gives reasons for this view, which in part at least appear to be sound. He further remarks: —

"The greater degree of crystallization in the older unstratified rocks may be explained, by supposing a more perfect fusion of the materials than in recent lavas, and greater slowness in cooling, under perhaps the more powerful pressure of a deep ocean." (*l. c.*, pp. 790, 791.)

He advances two theories for the origin of the "Primary Stratified Rocks."

1. "The stratified primary rocks are merely the detrital or fossiliferous rocks altered by heat. As these accumulated at the bottom of the ocean, being much poorer conductors of heat than water, they would confine the internal heat that was attempting to escape by radiation, until it became so great as to bring the matter into a crystaline state: but not great enough to produce entire fusion, so as to destroy the marks of stratification."

2. "This hypothesis supposes the primary stratified rocks to have been formed partly in a mechanical and partly in a chemical mode, by aqueous and igneous agency, when the temperature of the crust of the globe was very high, and before organic beings could live upon it."

President Hitchcock seems indeed to incline towards the second theory. (*l. c.*, pp. 796–798.)

In 1839 Mr. William Prescott's "Sketch of the Geology and Mineralogy of the Southern Part of Essex County, in Massachusetts," was published. (Journal of the Essex Co. Nat. Hist. Soc., 1852, I., pp. 78–91.) The rocks were described as gneiss, syenite, greenstone, porphyry, silicious breccia and brecciated porphyry, puddingstone, amygdaloid trap, and

magnesian serpentine, or verd antique marble. The syenite was said to pass into greenstone often by insensible shades. This paper locally is of considerable value. The red felsite of Saugus was described as jasper.

In 1854 the limestones of Eastern Massachusetts were referred to the Devonian by Dr. Hunt, who remarks as follows: —

"In the fourth class we include the crystalline limestone of eastern Massachusetts, which occurs in a great number of places in the towns of Bolton, Boxborough, Chelmsford, Carlisle, Littleton, Acton, Natick and Sherburne. It appears according to Hitchcock, in interrupted lenticular masses, lying in the gneissoid formation, or in the hornblendic slates, and occasionally presenting distinct marks of stratification. Still farther east at Stoneham and Newbury, we find crystalline limestone, sometimes magnesian, in irregular masses, lying in a rock intermediate between syenite and hornblende slate. Serpentine is found with that of Newbury; and at Lynnfield, a band of serpentine has been traced two or three miles N. E. and S. W. . . . . We have now to inquire as to the geological age of this great mass of crystalline rocks which is so conspicuous in Eastern New England. . . . . When we consider the geographical position of the Upper Silurian rocks in the Connecticut valley on the one hand, and the coal fields of southeastern Massachusetts on the other, we can scarcely doubt that the intermediate gneissoid, and hornblendic rocks, with their accompanying limestones, are the Devonian strata in an altered condition." (Am. Jour. Sci., 1854, (2) XVIII., pp. 198, 199.)

As late as 1863 the same view of the age of these limestones was held; while in 1861 Dr. Hunt especially stated, that we recognize nothing in New England or southeastern Canada lower *than the Silurian system.*" (Am. Jour. Sci., 1861, (2) XXXI., p. 403; 1863, XXXVI., p. 225; Geology of Canada, 1863, p. 592.)

In 1856 the first definite knowledge of the actual geological position of any of the rocks in the vicinity of Boston was obtained. Specimens of a trilobite, belonging to the genus *Paradoxides*, and a characteristic fossil of the Primordial, or Potsdam group of the Lower Silurian, had for many years been in the hands of scientific men in Boston; but the locality from which they had been obtained was not known. Finally, in 1856, the attention of geologists was called to these trilobites by the proprietors of a quarry in the argillite at Braintree, and the first notice of the occurrence of these fossils, and of their true locality, was given to the public by Prof. W. B. Rogers. (Proc. Bost. Soc. Nat. Hist., 1856, VI., pp. 27–30, 40, 41, 217; Am. Jour. Sci., 1856, (2) XXII., pp. 296–298; Proc. Am. Acad., III., pp. 315–319.)

Professor Rogers describes the argillite as being included between large masses of igneous rock, or syenite, and a dipping N. 20° W., at an

angle of about 45°. Dr. C. T. Jackson, later, gave the dip as to the north, at an angle of 50°. (Proc. Bost. Soc. Nat. Hist., 1856, VI., pp. 42–44.)

The next year, Mr. Isaac Lea, however, on examining the position of the fossils in the rocks, concluded that the dip was to the south, and to the amount of 68°. (Proc. Phil. Acad. Nat. Sci., 1857, IX., p. 205.) This latter appears, beyond doubt, to have been a correct statement of the direction of the dip, if not of its amount.

Dr. Hunt, in 1866, in his paper on the Laurentian Limestones, remarks of the crystalline limestones of Bolton and the adjoining towns in Eastern Massachusetts, that they

"resemble in geognostic and mineralogical characters, those of the Laurentian system. There are however not wanting reasons for supposing them to belong to a more recent geologic period, and the facts recently observed in Bavaria . . . . show, what was antecedently probable, that similar mineralogical characteristics may be found in crystalline limestones of very different ages." (Geol. of Canada, 1863–66, p. 197.)

This was reprinted without change in 1871, in the revised edition published in the Report of the Regents for New York. (See also Am. Jour. Sci., 1854, (2) XVIII., p. 200.)

In 1862, Mr. T. T. Bouvé claimed that he had traced, especially in Hingham, the passage of the conglomerate into a compact, homogeneous, almost jaspery rock. (Proc. Bost. Soc. Nat. Hist., 1859, VII., p. 183; 1862, VIII., p. 57.)

In 1867 Prof. Chas. H. Hitchcock remarked that there was reason to believe that the gneiss and hornblende schist of Andover belonged to

"Eozoic ages, perhaps as old as the Laurentian. . . . . The evidence consists chiefly in the fact that pebbles of the syenite, which is newer than the schist, occur in the Paradoxides slates near Boston, along with red jasper, green porphyry, and other rocks associated with the syenite. These slates form the lowest member of the Paleozoic series; hence the rocks from which the pebbles were derived are older than the Silurian, and must be Eozoic. Lithologically they resemble the Laurentian gneiss and syenite, in the typical localities." (Proc. Essex Institute, 1867, V., pp. 157–160.)

Professor Hitchcock probably had in mind the argillites and conglomerates, of whose age nothing definite is known, for in the Braintree argillite containing fossils, so far as the published records show, no such pebbles have been found by the numerous observers who have examined it.*

* Dr. Wadsworth has repeatedly examined the Braintree locality with a like negative result, so far as the occurrence of pebbles is concerned.

In the Bulletin of the Essex Institute, August 26, 1869, Vol. I. p. 106, the following report occurs: —

"Professor T. Sterry Hunt of Canada gave a geological description and history of the New England granite formation. The investigation of the last twenty years had gone very far to destroy the commonly received notion that granite was the foundation of all other rocks. They were beginning to learn that instead of the granites being the substrata of the globe, they were rather secondary or derived rocks, — that they were once great beds of gravel or sandstone which had subsequently become crystallized. After speaking of the probable age of New England granites, Professor Hunt said that in walking along the shore at Rockport, he could see that the granites were distinctly stratified with alternations of sandstone at different periods. This clearly showed their sedimentary origin, and probably identified them as being the same as the granites north and south, and thus enabled them to class them among the Devonian rocks. Perhaps ten thousand or fifteen thousand feet beneath them might be beds holding fossils of the Silurian type, — the same beds, perhaps, as those cropping out at Braintree. As compared with the rocks at Braintree, the granites probably were of very recent origin. From careful analysis it was ascertained that the Rockport granite contained traces of living organisms. He would mention that with reference to aerolites, chemists had found in them traces which by them were regarded as certain evidence of the remains of organic life."

October 19, 1870, Dr. Hunt said that the granites of Cape Ann and of Quincy were probably intrusive, (Proc. Bost. Soc. Nat. Hist., 1870. XIV., p. 46,) which agrees with the view advanced by him in a paper read before the American Association for the Advancement of Science. August 20, 1870. (Am. Jour. Sci., 1871, (3) I., p. 85.) In 1873 the granites of Rockport were stated by him to be distinctly eruptive. (Proc. Bost. Soc. Nat. Hist., 1873, XV. p. 262.) These statements, then, according to Dr. Hunt's published views (Chemical Essays, p. 9), necessitate a depression of the sediments, out of which the granite was formed, into the *solid* earth to the zone of igneo-aqueous fusion, where the eruptive granite was formed. Part of the original sandstone, however, remained in this zone unchanged: while beneath, at a depth of ten or fifteen thousand feet lower, the Silurian rocks retained their original character, their fossils remaining unaffected; and this took place in the "same beds, perhaps, as those cropping out at Braintree," the rock at that place being, as is well known, an easily fusible argillite. Then this granite was raised again to the surface, thus carrying the argillite unmetamorphosed twice through the zone of igneo-aqueous fusion.

In November, 1869, Mr. E. Bicknell announced that *Eozoön Cana-*

dense had been found in the serpentine (limestone) quarry at "Devil's Den," Newbury. Prof. Hyatt then remarked that "the rocks of this county [Essex] had been hypothetically referred to the lowest known series of Laurentian strata"; but that this was the first instance "in which any positive evidence has been produced of their actual age." (Bull. Essex Institute, 1869, I. pp. 141, 142; American Nat., 1869, III., pp. 498, 499.)

In 1869, Prof. N. S. Shaler remarked: —

"There can be no doubt that the syenites, which make up so large a part of the exposed rocks of Eastern Massachusetts, are the oldest materials found in this region. . . . . The most remarkable fact which has come under my observation is the existence of planes of separation in this syenite, which cannot be referred to joints. . . . . That I am not mistaken in referring these fractures to bedding, is, I believe, abundantly proven by the details of structure of the syenite itself, as well as by the relations it bears to the unquestionably stratified rocks which rest upon it. . . . . There are visible on the surface of considerable sheets of this rock, laid bare in the Mitchell quarry near Quincy, splitting along what I believe to be the plane of stratification, markings indistinguishable from ripple marks. . . . . If these syenites were of igneous origin, if they had been poured out before the deposition of the adjacent stratified beds, or thrust through them in a state of fusion, we should expect to find the usual marks of such actions. In the first of these cases the later sedimentary deposits would be found lying unconformably upon the syenite without any indication of transition; in the second we should expect to find a clear line of contact between the syenite and the sedimentary rocks, such as is always to be found where an intrusive mass of trappean matter cuts more ancient rocks. What we do find is that the imperfect bedding of the deeper portions of the syenite becomes more and more clearly defined as we pass towards the exterior of the mass, and gradually passes into unquestionably sedimentary rock. Every stage of this transition is not clearly seen, but enough is visible to satisfy any one that it really exists. The first rocks of quite unquestionable stratified origin, lie directly to the north of the Quincy syenite hills, and consist of clearly bedded sandstones, approaching quartzites in their character. . . . . Their general dip is northerly, with a variable angle of inclination which may be roughly averaged at twenty degrees. . . . . Running the same north course across the break, we come upon the lowest of the Braintree series. . . . . Its dip corresponds with the general inclination observable in the supposed stratification of the syenite, as well as that of the quartzites immediately above it. The whole of this Braintree series is fossiliferous, ... and although much changed by metamorphic action, it is easily perceived that the whole set of beds contains no trace of shore deposits. Immediately beyond the exposure of the Braintree beds at Hayward's Landing, a dislocation has brought the thin bedded quartzites again to the surface. The alteration in these is so great that

the rock has assumed something of the appearance of gneiss, and would by some be classed in that group of rocks. . . . . The uniform dip away from the Quincy Hills, shown by all the stratified beds on their flanks, may be regarded as sufficient proof that their elevation came after the deposition of these beds." (Proc. Bost. Soc. Nat. Hist., 1869–71, XIII., pp. 172–178.)

While to one not acquainted with the geological structure of the region described, Professor Shaler's paper may appear conclusive; the facts, that the granite presents exactly the same intrusive relations to the argillite that he says it should have if eruptive; that he mistook for sandstones and quartzites the Quincy granite itself; that the fossils in the argillite show that its dip is diametrically the opposite of the one he has assumed; that his supposed ripple-marks were the not uncommon wavy fracture of granite; and finally that his assumed stratification planes are joint or structure planes, — leave his conclusions without any foundation.*

Professor Shaler points to the relations between the argillite and conglomerate as exposed while the excavations were being made for the construction of the Chestnut Hill Reservoir. There he found that the argillites lay beneath with conglomerate overlying, then more argillite and above this the conglomerate, indicating it as probable that the argillites and conglomerates in the vicinity of Boston form the same series of beds, which he considered to belong to the primordial era. (*l. c.*, p. 176.)

In 1870, Dr. Hunt, on account of the finding of *Eozoön Canadense* in limestones at Newbury (erroneously said to be in the adjoining town, Newburyport) and Chelmsford, regarded the associated rocks as being of Laurentian age, saying: —

"These specimens from Chelmsford, it should be said, have been examined and satisfactorily identified by Dr. Dawson. The argument from mineralogical and lithological resemblances in favor of the Laurentian age of the limestone in question is therefore now supported by the undoubted presence in them of *Eozoön Canadense*."

The rocks about Newbury, which it will be recollected were united by Prof. C. H. Hitchcock to the Cape Ann and Quincy hornblendic

* In the preceding paper of Professor Shaler the misnomer of "Cambridge slates" was applied to the argillites so well exposed in Somerville, and which properly should have been called by the name of that city instead of Cambridge. The truth is, that the locality from which they were named was erroneously supposed to be in Cambridge, when in fact it is in Somerville. This locality was again erroneously said to be in Cambridge in Professor Shaler's "Question Guide to the Environs of Boston," 1875, p. 20. No exposure of the argillite is known to exist in Cambridge, although it has been found there by digging.

granites (syenites), Dr. Hunt regards as unlike the latter. (Am. Jour. Sci., 1870, (2) XLIX., pp. 75–78.)

In a paper published in 1870, but said to have been read before the American Association in August, 1869, Dr. Hunt remarks: "The gneiss of Eastern Massachusetts is, as I have recently found, in part of Laurentian age." (Am. Jour. Sci., 1870, (2) XLIX., p. 184.) Again, the same year, the "diorites and porphyries" at Newburyport, Salem, Lynn, and Marblehead were referred to the Cambrian, which Dr. Hunt at that time appears to have regarded as the equivalent of the Huronian. (Am. Jour. Sci., 1870, (2) L., p. 89.) Further, of his Terranovan series he states: —

"The micaceous and hornblendic schists, with interstratified fine grained whitish gneisses (locally known as granites) which I have seen in Hallowell, Augusta, Brunswick and Westbrook, in Maine, appear to belong to the same series; which will also probably include much of the gneiss and mica-schist of Eastern New England. If this upper series is to be identified with the crystalline schists which, in Hastings County, Ontario, overlie, unconformably, the Laurentian, and yet contain *Eozoon Canadense*, the presence of this fossil can no longer serve to identify the Laurentian system. To this lower horizon however, I have referred a belt of gneissic rocks in Eastern Massachusetts, which are lithologically unlike the present series, and identical with the Laurentian of New York and Canada." (*l. c.*, p. 88.)

In October, 1870, Dr. Hunt stated regarding the geology of Eastern Massachusetts, that

"the rocks which we have seen may be considered in three classes. A, the crystalline stratified rocks; B, the eruptive granites; C, the unaltered slates, sandstones and conglomerates. The former of these may be separated lithologically into two divisions; the first being the quartzo-feldspathic rocks. Among these are included the felsite-porphyrites of Lynn, Saugus and Marblehead, with their associated non-porphyritic and jasper-like varieties. . . . . Associated with them is a granular quartzo-feldspathic rock, which is often itself porphyritic, with feldspar crystals, and sometimes appears as a fine grained syenitic or gneissoid rock, often distinctly stratified. . . . . These rocks are seen intimately associated with the porphyry on Marblehead Neck, also in Marblehead, and underlying the argillites of Braintree and Weymouth. The second division of the rocks of class A includes a series of dioritic and chloritic rocks, generally greenish in color, sometimes schistose, and frequently amygdaloidal. . . . . This series holds a bed of dolomite at Stoneham, and serpentine in Lynnfield, ... the greenstones of Dr. Hitchcock . . . . ; and also his varioloid wacke, under which name he describes the green and chocolate-colored amygdaloidal epidotic and chloritic rocks of Brighton, and the somewhat similar rocks of Saugus. . . . . I regard these two types of rocks as

forming parts of one ancient crystalline series, which is largely developed in the vicinity of Boston, and may be traced at intervals from Newport to the Bay of Fundy, and beyond. To this same series I refer the great range of gneissic and dioritic rocks with serpentines, chloritic, talcose and epidotic schists which stretches through western New England. These ancient rocks are in various places penetrated by intrusive granites, which are generally more or less hornblendic — the syenites of Hitchcock and others. . . . . In this vicinity, besides the granites of Cape Ann and of Quincy, which probably belong to this class, examples of intrusive granites (or syenites) are well seen in Stoneham and in Marblehead, where they cut the greenish chloritic rocks, and on Marblehead Neck, where they are erupted among the felsite-porphyries. In all these places the phenomena of disruption and enclosure of fragments of the broken rock in the granite are well seen, the lines of contact being always sharp and well-defined. . . . . All of these rocks, the granites included, are on Marblehead Neck traversed by dykes of intrusive greenstone, which are sometimes very similar in aspect to certain of the bedded diorites of A. Of the rocks of class C, the unaltered argillites of Braintree, holding a primordial fauna, were observed by Prof. Shaler and myself to rest directly upon a hard porphyritic felsite of the ancient series. . . . . Reddish granulites directly underlie the black argillites of Weymouth, and the quartzites with conglomerates and argillites of Chestnut Hill Reservoir, and of Brighton near by, are in several places observed in contact with the old dioritic and epidotic rocks already noticed. The Roxbury conglomerate was observed to contain pebbles of the felsite-porphyries, diorites and intrusive granites of the older series, besides, as already remarked by Hitchcock, fragments of argillaceous slate. In this connection may be noticed a remarkable recomposed rock long since correctly described by the same careful observer, as an aggregate of broken-up and recemented felsite-porphyry. . . . . He observed it at Hingham and Cohasset, and Mr. Hyatt has since found it on Marblehead Neck, resting directly on the parent rock, and very firmly cemented. The unequal weathering of the surface, however, clearly shows both its conglomerate character and the inferior hardness of the cement. . . . . The fact that the primordial strata of Braintree have suffered no metamorphism is the more significant, since the beds of similar age in New Brunswick and Newfoundland rest unconformably on crystalline strata supposed to belong to the same ancient series that underlies the Braintree beds, and are, like these, unaltered sand and mud rocks." (Proc. Bost. Soc. Nat. Hist., 1870, XIV., pp. 45–49.)

This paper of Dr. Hunt's secured an amount of acceptance amongst the local geologists far beyond that to which it was entitled; especially when it is remembered that it is based on simple assertion, without any evidence in support of the positions taken. Moreover, these views were largely in opposition to his life-long teachings, down to 1869, and concerning which statements had been made as positive in character as those of an opposite nature here upheld. From this time onward, how-

ever, most of the geological papers relating to Eastern Massachusetts were based on the views of Dr. Hunt as here presented. It may be noticed that the Quincy granite near the Braintree argillite quarry, which Professor Shaler regarded as a quartzite or sandstone, Dr. Hunt calls the same as the Marblehead felsite.

In Mr. Walling's Atlas of Massachusetts, published in 1871, Prof. C. H. Hitchcock gave a Geological Description of the State (pp. 17–23). He writes: —

"In New England the older strata have been greatly *metamorphosed*, i. e., have been transformed from the original sedimentary sandstones, clays, and limestones into granite, gneiss, schists, slates, and other crystalline rocks; and during the process of change the remains of the primeval animals and plants have been mostly obliterated."

To the Eozoic formation he refers

"the syenite and porphyry of Eastern Massachusetts; and possibly the gneiss and granite of Plymouth and Bristol counties, and the gneiss and hornblende schist of Middlesex county. . . . . Associated with the Paradoxides slates of Hingham, is a conglomerate composed of pebbles of syenite and porphyry, like the ledges of these rocks occupying so much of the area in Essex, Middlesex, Norfolk, and Plymouth counties. The inference is irresistible, that these unstratified rocks existed as ledges before the birth of the trilobite, occupying the very oldest Paleozoic bed, and therefore they must be of Eozoic age. Lithologically, there is a slight resemblance between some of the porphyritic rocks and the Huronian group of Canada and Michigan."

Prof. Hitchcock is in error here, since the age of the Hingham argillite is not known, and if it were, the finding of fragments of an eruptive rock in a sedimentary one is no proof of difference in geological age.

In his Notes on Granitic Rocks Dr. Hunt says: —

"Felsites and felsite-porphyries are well known in Eastern Massachusetts at Lynn, Saugus, Marblehead and Newburyport. . . . . These rocks are throughout this region distinctly stratified, and are closely associated with dioritic, chloritic and epidotic strata. They apparently belong, like these, to the great Huronian system." (Am. Jour. Sci., 1871, (3) I., p. 84.)

Later, Prof. A. Hyatt remarked: —

"The porphyry of our vicinity, whether Lynn, Marblehead or Newburyport is a recomposed rock, a conglomerate composed of more or less rounded pebbles of more ancient banded porphyry. . . . . We meet in the neighborhood of Newburyport with a transition rock made up partly of porphyry, and then with stratified diorites and slates, which surround the porphyry outcrop on the sea-face. . . . . The northwesterly dip, and northeasterly strike of these diorites and slates, and the presence of slate rocks in Topsfield and Middleton,

are difficult to account for unless we imagine the porphyries to be interstratified with them. The succession of the strata in this part of the country then would be Eozoönal limestones and serpentines, then slates, then the porphyries of Kent's Island and Lynn, then slates and diorites, and lastly, the porphyries of Marblehead Neck. Either this is the explanation or else we have several anticlinal axes or folds in the porphyry. In either case all the porphyries are probably older than the Eozoönal rocks of Newburyport, and underlie them. The porphyry of Marblehead Neck has the stratified micaceous rocks . . . . lying upon its southeastern face, with dip and strike precisely conformable to the more ancient shore-line formed by the porphyry itself. The porphyry of Lynn has upon its eastern face the outcropping edges of an enormous overflow of igneous granite. . . . . In fact, all the difficulties of the survey have arisen from the enormous sheet, or rather, sheets of igneous rocks, for there seems to have been several which overspread the surface of the country." (Bull. Essex Inst., 1871, III., pp. 49–53.)

Dr. Hunt, in reply to Prof. Hyatt's communication, remarked as follows: —

"I have expressed the opinion that the porphyries of the eastern coast of Massachusetts are stratified rocks, belonging, together with their associated diorites and slates (greenstones, chloritic and epidotic rocks), to the Huronian system, or Green Mountain system. As regards the limestones with Eozoön, from eastern Massachusetts, which in the *American Journal* for Jan., 1870, I referred to the more ancient Laurentian system. I have in that same journal for July, 1870, pointed out the fact that the Eozoön of Hastings county, Ontario, occurs in a series of crystalline schists which I consider newer than the Huronian, and the equivalent of the White Mountain gneisses and mica-schists, so that, as I there remark 'the presence of this fossil can no longer serve to identify the Laurentian system.' . . . . It will therefore remain for farther study, to determine how far the crystalline limestones of eastern Massachusetts belong to the Laurentian, and whether some of them are not included in one or the other of the newer systems of crystalline schists. The porphyry conglomerate noticed by the late President Hitchcock and described by Prof. Hyatt, are referred to in my paper of last October, mentioned above. This rock is, I conceive, to be distinguished from the old Huronian porphyry, on which it often reposes, and from the ruins of which it is derived." (Bull. Essex Inst., 1871, III., pp. 53, 54.)

If the reader will refer to our quotation of Dr. Hunt's paper relating to the Eozoön, or to the original (Am. Jour. Sci., 1870, (2) L., p. 88), he will see that the remark regarding the value of that supposed fossil was a *hypothetical*, and not a *positive* one, as Dr. Hunt now claims it to have been. In connection with the above quotation from the Bulletin of the Essex Institute it may be interesting to remember that a little over a

year later Dr. Hunt denied that he had held that the White Mountain series was younger than the Green Mountain or Huronian series. (Am. Jour. Sci., 1872, (3) IV. p. 51.)

In his address before the American Association, Dr. Hunt still held that the gneisses and crystalline limestones of Chelmsford, etc. were Laurentian, and said : —

"The uncrystalline argillites and sandstones, holding Paradoxides, at Braintree, ... overlie unconformably crystalline schists of the second series," (Huronian or Green Mountain). (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 10, 32.)

In 1875 Mr. W. W. Dodge classified the rocks of Eastern Massachusetts as follows (Proc. Bost. Soc. Nat. Hist., 1875, XVII., pp. 388–419) : —

I. Crystallines.
II. Stratified Rocks { A. Slates. B. Conglomerates.

Of the crystallines he says : —

"They underlie unconformably strata holding Paradoxides, etc., and probably formed hill or island ranges very early in the history of this continent. . . . . For the most part, metamorphism has been so complete that these rocks have lost almost entirely their probable original character."

Of the syenite he states : —

"The abundance of quartz seems to point rather to metamorphic than igneous condition, and there is probably no doubt that they are chiefly of sedimentary origin. . . . . Above Spy Pond in Arlington, there are slaty rocks which pass through fine grits to coarse sienite by various stages. So, too, in Medford."

Under the term "porphyry" he makes four divisions, and thinks that some of the slates may have been so altered as to closely resemble porphyry. He appears to hold that all the rocks included under the term "crystallines" are of sedimentary origin, and have acquired their present character by metamorphism. The eruptive rocks of this region Mr. Dodge holds to have been derived from the "crystallines," remarking : —

"As a matter of fact, so close is the resemblance in chemical composition, appearance and minerals developed in them, of the eruptives among the slates and conglomerates, to the more fusible portions of the crystallines, that it seems almost unreasonable to doubt that the former were derived from among deep lying masses of the latter."

Of the Brighton melaphyr (amygdaloid) he states : —

"Whether these rocks as a whole are of the crystalline stratified class, or whether they have undergone such change as to entitle them more appropri-

ately to a different name, this is certain, that some of them are found cutting the slate and conglomerate, and poured out over them, and that near the contact the slate is greatly hardened."

Of the "stratified rocks" Mr. Dodge remarks: —

"Between the older rock bands described lie certain more recent and more clearly stratified rocks. The more recent age of these is shown beyond dispute by their position in relation to the underlying crystallines, as well as by the fact that they are composd of detritus of the latter, which may not only be so recognized, but even may at times be referred to the source from which it was probably derived."

The "stratified rocks" were separated into slates and conglomerates, although much argillite was united with the latter. The "slates" included not only the Braintree argillite, but also many of the other argillite deposits, and in common were referred to the St. John group. He further states: —

"In all the localities they are much disturbed by intrusions of igneous rock (which is sometimes poured out over them), are faulted, hardened and distorted."

Mr. Dodge considers the conglomerate as overlying the Braintree argillite, and as being probably of Carboniferous age. (Proc. Bost. Soc. Nat. Hist., 1875, XVII., pp. 411, 412.) Dr. Hunt states in the same volume that he regards the argillite about Boston Harbor as being of the same age as the Braintree argillite. (Ibid., pp. 486–488.)

The following is a quotation embodying remarks made by Dr. Hunt, at a meeting of the Boston Natural History Society, in the same year: —

"The crystalline rock, ... seen in contact with the fossiliferous Lower Cambrian (Menevian) strata of Braintree, Mass., is clearly a variety of the feldspar-porphyry or orthopyre, which is so abundant along the eastern coast of Mssachusetts, Maine and New Brunswick, and which passes on the one hand into a jaspery petrosilex, and on the other, into a finely granular, almost granitoid rock. . . . . The porphyries of Lynn, Marblehead and Salem, and the so-called jaspers of Saugus and Newbury, belong to it. This rock is identical with the porphyry which accompanies the crystalline iron ores of southeastern Missouri, and is also well displayed on the north shore of Lake Superior. It is, in all these localities, distinctly stratified, and has been by the speaker referred to the Huronian series of rocks. . . . . This porphyry, in the form of pebbles, often forms conglomerate beds in the Keweenaw or copper-bearing series of Lake Superior, as is well seen in the Calumet and Hecla, and the Boston and Albany mines.

"As regards the relations of the eruptive granites of our Eastern coast to the Braintree fossiliferous slates, Dr. Hunt remarked that the granites on Marble-

head Neck, which resemble those of Cape Ann, are seen to cut the still older porphyries." (Proc. Bost. Soc. Nat. Hist., 1875, XVII., pp. 508–510.)

In 1876 Mr. T. T. Bouvé called attention to his views regarding the derivation of the felsites in the vicinity of Boston from the metamorphosis of the conglomerates. He remarked that, in 1870,

"Professor Niles distinctly stated that he had traced in Dedham the conglomerate until it passed into porphyry. He had noticed the effects of metamorphism where dikes occurred, and he believed that many of our porphyritic rocks were formed from the conglomerate. These views I sustained by referring to my own observations, expressing myself satisfied that the porphyries of our vicinity, as well as the amygdaloids, were altered conglomerates. Dr. Hunt closed the discussion by saying he was confident that at Marblehead these rocks were not altered conglomerates. They were derived rocks, but from the primitive parent rock on which they rested. . . . . In conclusion I wish not only to re-express my belief in the derivation of these felsites from conglomerates, but to go one step further, and include among the rocks having the same origin, some at least of the underlying sienites. . . . . But I refrain from expressing more on this point, simply because my own observations in the field have been so limited, but will ask if the reputed succession of our rock deposits is not itself very suggestive.

"Conglomerate.

"Compact Feldspar, gradually passing into Porphyry.

"Porphyry gradually passing into a rock intermediate between Porphyry and Sienite.

"Rock intermediate between Porphyry and Sienite.

"Sienite.

"Now if this gives the true succession of our rocks, ... I ask if it be not a fair inference that the causes that led to the changes in the higher portions of the series, affected all, only to a much greater degree the lower; that the heat and aqueous menstruum that softened and partly changed some of the conglomerates of the upper portion forming the felsite conglomerate, ... and which melted the succeeding strata so as to produce first felsites without crystals, and below these the true porphyries, may not also by its greater intensity so thoroughly have melted down still lower strata of sedimentary rocks (conglomerates and slates perhaps), as to entirely resolve them into their original elements, recrystallize them and thus have formed sienites, some of which may have even subsequently played the role of eruptive rocks; for it by no means follows that because a rock has been sedimentary that it may not also have become likewise eruptive by being forced upward when in a semi-fluid state." (Proc. Bost. Soc. Nat. Hist., 1876, XVIII., pp. 217–220.)

Prof. Hyatt, in support of Mr. Bouvé's views, remarked in regard to the felsite of Marblehead Neck:

"The porphyries appear to overlie the Salem syenites unconformably, and together with them are cut by at least two series of dioritic dykes. . . . . The porphyries, though varying greatly in aspect and in composition, are nevertheless but one formation, and derived from a vast conglomerate which appears in Lynn, Saugus, and Marblehead, and is reported to occur under the granites on the Beverly shore. The originally conglomerate nature of the entire deposit is inferred by extensive observations made by myself at Marblehead Neck, and by my assistant, Mr. W. O. Crosby, in Saugus, and the general identity of the purely crystalline porphyries of Lynn with those of Marblehead Neck, which are undoubtedly merely altered conglomerates. . . . . The change into the felsite is the most instructive, since here it is possible to trace the included pebble of dark colored, banded porphyry through all stages until it becomes a mere spot in the light colored matrix. During this change the pebble disappears by some process by which the structure is altered from without, the centre being the last point to lose its distinctive coloring or structure. . . . . The fact seems to me unquestionable, ... that both a felsite and a true porphyry were formed out of a conglomerate, without any perceptible change having been made in the form of the contained pebbles." (Proc. Bost. Soc. Nat. Hist., 1875–76, XVIII., pp. 220–225.)

Professor Hyatt points out that the felsite pebbles in the conglomerate are different from the felsite formed from it, and holds that through pressure or otherwise the pebbles form the thin laminæ seen in the banded felsite. The reader is referred to his very interesting description of the imaginary processes, since it is too lengthy to transcribe here. (Ibid., pp. 223, 224.)

Mr. W. O. Crosby, in his Report on the Geological Map of Massachusetts, 1876, says (pp. 7, 8, 10, 11) : —

"The Eozoic rocks of Massachusetts may to a large extent at least be divided lithologically and chronologically, into three divisions, which, stated in their order of sequence, are the Norian, the Huronian, and the Mont Alban. I weigh my words well when I describe these divisions as both lithological and chronological ; for, ... I do not hesitate to affirm that the lithological characters of the divisions which have been worked out among the crystallines of this region, — the chronological and geographical distinctness of which I cannot doubt — are as unlike as the faunæ of any two successive geological formations."

This statement was in substance again affirmed in 1880. Of the Norian he writes : —

"The rocks of this formation, though frequently stratified, seem in general to have been somewhat fluent, and usually exhibit more or less extravasation; but doubtless in some cases the metamorphic action has stopped short of this extreme term, though destroying all traces of bedding. In many places . . . .

the entire formation seems to have been fluent, and the extravasation has been so extensive that the character of the rock changes nearly every rod. One important fact should be noted here, viz.: nowhere in this region does the Norian series appear to be cut by eruptives belonging to another formation, for all the extravasated rocks of this system may be easily referred to, or shown to be derived from, its stratified members. . . . . At Nahant we find slates, believed to be of Primordial age, resting upon the Norian diorites, which have been extravasated through the slates, producing extensive alterations. The coarse grained, readily disintegrating, exotic diorites, so extensively quarried in Medford, and also occurring in Somerville and Brookline, are, doubtless, extruded portions of this same series, which is the probable seat of many of the eruptive rocks, especially diorites, cutting the newer formations. . . . . Here is the real base of our geological column." (Report, 1876, pp. 8, 10, 11.)

We have in Mr. Crosby's work above quoted strongly formulated the principle that any dike cutting another rock is older than the rock it cuts, and is itself of distinctly recognizable age, — a perfectly logical result of Dr. Hunt's teachings. The "Norian" dikes in Medford, Somerville, and Brookline were found by Dr. Wadsworth to be diabase (Proc. Bost. Soc. Nat. Hist., 1877, XIX., pp. 217–237), and to belong to old basaltic eruptions. We must then conclude, according to this view, that all basaltic rocks, even the outflows of modern volcanoes, are derived from the Norian system, and are to be mapped and called Norian. To be sure we find such dikes cutting the Laurentian of other regions, but in this latter case they were doubtless extravasated downwards, as advocated recently by Professor Shaler (Mem. Vol. Bost. Soc. Nat. Hist., pp. 3–15). Dr. Wadsworth has also carefully studied the dikes both in the so-called Laurentian and Huronian, and can affirm their unity, both in macroscopical and microscopical characters.

Mr. Crosby divided his supposed Huronian rocks into the following series: hornblendic granite, felsite, diorite, stratified rocks, and limestone. Of the first series it was said: —

"That these granites are mainly exotic, can scarcely be questioned, for we have seldom far to look, to find, in the form of enclosed angular fragments of clearly stratified rocks, evidence of their extravasation, and near the boundaries of the granites we usually find them cutting the adjoining rock, especially if that is stratified, in a manner incompatible with any theory that would regard them, in their present condition, as indigenous or endogenous. Nevertheless it is doubtless true, as suggested by Prof. N. S. Shaler, and later by Mr. T. T. Bouvé, that these granites have been derived from sedimentary rocks, and have simply reached the final term in the metamorphic process — igneous, or more probably, igneo-aqueous fusion." (Report, 1876, p. 14.)

Mr. Crosby also states emphatically that "this rock [the granite of Rockport] is destitute of mica, or at least its presence is a very rare occurrence." Dr. Wadsworth showed in 1878 (Proc. Bost. Soc. Nat. Hist., XIX., pp. 309–316) that this was an error, so far as it concerned at least ninety-five per cent of the rock then quarried at Rockport. It was also pointed out, that a brief inspection of the two buildings in which Mr. Crosby had for many years been working would afford evidence of the mistake, as would also an examination of the buildings on almost any street in Boston. The correctness of these statements of Dr. Wadsworth was acknowledged by Mr. Crosby in 1880 (Contributions, p. 28).

Of the felsite Mr. Crosby writes (Report on the Geological Map of Massachusetts, 1876, pp. 17–21):—

"In general it is a structureless rock, showing no trace of bedding; but at Dungeon Rock in Lynn, it is distinctly stratified, a dense, black variety being interstratified with a crystalline dioritic variety; and going northward in Melrose, the porphyritic character gradually disappears, the felsite becomes more siliceous, and gradually becomes interstratified with quartzite and hornblende slates. The transition is so gradual that it is impossible to define the boundary between the stratified and unstratified felsites, which proves there is no break, no natural division here. In Melrose and Malden, and at other points the porphyritic felsites exhibit frequent local passages into granite and diorite. It seems probable that considerable portions of this rock have been in a more or less fluent state, this can scarcely be doubted on the west shore of Wenuchus Lake in Lynn, where the tongue of granite penetrates the felsite; and on Marblehead Neck and the neighboring islands, there is abundant evidence of the softening and extravasation of portions of the rock. Notably on Marblehead Neck, also on Red Rock in Lynn, and at the Pirate's Glen in Saugus, and, perhaps, at other points, this felsite exhibits traces of a conglomerate origin. . . . . There are in this region two principal varieties of 'banded' or laminated felsite, which differ widely in their origins; first, that in which the banding is due to a conglomerate origin, having been produced by a flattening of the pebbles of the conglomerate; . . . . and second, the much more abundant and widely distributed variety in which the banding represents the original bedding of the rock. . . . . The banding commonly results from the interlamination of thin layers of quartzose and feldspathic materials. The thickness of the laminæ usually varies from a mere line to one-sixteenth of an inch, and seldom exceeds one-eighth of an inch. That this banding really represents stratification is proved by the regularity and continuity of the bands, since a banded structure due to the flattening of the pebbles of a conglomerate would necessarily exhibit little uniformity in the thickness of the laminæ, and I find it difficult to conceive of pebbles flattened to such an extent as to produce continuous layers of uniform thickness and yards in

extent; and it is also proved by the constancy of their strike and dip. It undoubtedly becomes more crystalline, more granitic, and passes into the Quincy granite, and the granite of Dedham. It passes into fine grained granite toward the east and south. Good examples of the granitoid felsite, of small extent, occur on Lowell's Island and the north-west shore of Marblehead. . . . .

"On Marblehead Neck the breccia, which is here more properly a conglomerate, becomes at some points, especially on Lowell's Island, a coarse, gritty, feldspathic sandstone, and both the conglomerate and sandstone pass into compact felsite, the former in two distinct ways, which, although observable at several points in this region, are best exemplified here. These two modes of metamorphism are: (1) By a blending together of the pebbles and paste, whereby the outlines of the former are lost, or, when the process is not complete, can only be seen on weathered surfaces. (2) By a flattening or drawing out of the pebbles into thin lenticular laminæ, which, more or less coalescing at their edges and lying in parallel planes, produce a stratified appearance in the rock, and give rise to a laminated or banded structure closely resembling that already described, due to original sedimentation. . . . . It is further shown that the massive, structureless felsites, have probably been largely derived from massive, obscurely stratified, feldspathic slates, while the normally banded felsite represents a finely and distinctly stratified slate."

Of the diorites he remarks (Report, pp. 22, 23): —

"The diorite, like the granite, varies greatly in texture and composition. . . . . In composition it has a wider range; as already stated, it passes, by an admixture of quartz, into fine-grained hornblendic granite; and it is no less prone, by losing hornblende, to pass into felsite. Fine examples of the transition between diorite and felsite may be seen in Greenwood and Stoneham. . . . . The areas colored as diorite on the map . . . . embrace a great amount of fine grained hornblendic granite. . . . . Any observer of these two rocks will agree with me that they admit of neither a lithological nor a geographical separation. As a rule they are both eruptive, and over large areas they have been extravasated through each other so extensively, and the action has been so mutual, that the complication is complete; and I have long been accustomed to speak of them as 'mixed rocks'; and I know of no term that will better express their relations, lithologically or petrologically."

Of the stratified rocks he states (*l. c.*, pp. 23–27): —

"As already stated, we find, on going northward through Melrose, the porphyritic felsite, gradually becoming less porphyritic and assuming a stratified appearance. North of Howard Street traces of stratification are common, though porphyritic felsite occurs as far north as Greenwood. North of Central Brook, in Saugus, the felsites are chiefly stratified, the bedding increasing northward, are largely quartzose, passing into quartzite, and are frequently interstratified with hornblende slate and stratified diorite. No observer, who

has been over this ground, can doubt that these different rocks are stratigraphically inseparable. Along the eastern border of this area of stratified rocks, one can find beautiful examples of the passage of stratified diorite and hornblende slate into the eruptive diorite and fine grained hornblendic granite. There is nothing abrupt about these transitions, the gradation is perfect. . . . . About four miles farther northwest, in Reading, ... we find the rocks shading insensibly into eruptive diorite and granite. . . . . The large area of diorite stretching from Stoneham to Weston includes numerous small patches of stratified rocks — hornblende slate and petrosilex. . . . . They pass frequently into the enclosing rock, showing that they are mere remnants of the stratified group, which yet preserve traces of the structure once possessed by the whole mass of the rock. . . . . It thus becomes evident that this diorite, the so-called 'Salem syenite,' has, like the diorites elsewhere, resulted from the extreme metamorphism of the stratified group. . . . . I have already indicated that much of the hornblendic granite has been derived by metamorphism from felsite. . . . . I have shown that this is the probable origin of all the Huronian granites. It is demonstrated that the most, and probably all, of the felsites of this region, are now, or were originally, stratified, and may, therefore, be logically included in the stratified group. . . . . The rocks of this area consisted once, speaking generally, of stratified felsite, hornblende slate and stratified diorite only, which were then, and are even now, so related stratigraphically, and exhibit such frequent lithological transitions, as to prove them to be members of one and the same unbroken series ; and that the felsites, by metamorphism, have given rise to granite, the hornblende slates, in like manner, to fine grained hornblendic granite approaching diorite, and the stratified diorite to eruptive diorite."

Of the Huronian formation in general it is stated (*l. c.*, pp. 27–29) : —

"All the stratified rocks of this formation north and west of Boston, including besides the so-called stratified group, the dolomites and stratified felsites, dip, with few and unimportant exceptions, to the northwest. . . . . Since the limits of the different rocks are marked by gradual transitions, which precludes the existence of faults of any great extent ; and since there are no apparent repetitions of the different rocks, which precludes the existence of considerable folds of the strata ; we are forced to the conclusion that the geographical arrangement corresponds to the stratigraphical succession ; and the rocks to the south-east must underlie those to the north-west — the felsites must be older than the hornblende slates and diorites. . . . . Since the granites are more intimately associated with the felsites than any other of the stratified rocks, and are probably derived from them ; and since the exotic granites occur as eruptives through *all* the stratified rock ; the inference is plain that the granites belong normally at the bottom of the series, and may be taken to represent the lower portions of the felsite. . . . . The oneness of formation has been established ; it is proved by its petrological, its lithological, and as I have else-

where shown its chemical characters. I have pointed out, in the preceding pages, that it distinctly *overlies* the Norian rocks ; and it no less clearly *underlies* the Mont Alban. It exhibits much greater disturbance than the Mont Alban, but less than the Norian ; and near the common boundaries of this series and the Mont Alban, the gneiss of the latter is cut by the eruptive granite and diorite of the former. And since this series so closely resembles, in its internal characters and its external relations, the Huronian of other regions, we are bound to conclude that it *is* the Huronian."

Of the argillite and conglomerate in the vicinity of Boston, Mr. Crosby remarks (*l. c.*, pp. 40–42) : —

"Although the fossils characteristic of the Acadian group have been found at only one locality in Massachusetts, viz., Hayward's quarry, in Braintree, yet most observers agree that the greater portion of the slates in the vicinity of Boston are probably of Primordial age ; and I have so represented them on the map. . . . . The conglomerate so well developed about Boston, and widely known as the Roxbury conglomerate, is lithologically identical with the carboniferous conglomerate of Bristol county and Rhode Island, and seems to be similarly related to the Primordial rocks. It has been frequently referred to the Carboniferous horizon ; and, in view of the facts just cited, and the absence of any positive evidence to the contrary, this is certainly the most probable view of its age."

Dr. Wadsworth published, in 1877, a description of the dikes in certain portions of the Boston basin, based on a study of their field relations and microscopic characters. He showed that the supposed hornblende was in general augite, and that the rocks were old basaltic ones belonging to the melaphyr and diabase varieties. It was also proved that dikes of two, if not three, distinct periods existed here, and that the later faulted the earlier ones. In 1878 he also showed that the Rockport granite was of two varieties, a micaceous and a hornblendic one. These were found by careful observation on continuous exposed surfaces to pass into one another, usually having an intermediate grade containing both hornblende and mica. (Proc. Bost. Soc. Nat. Hist., XIX., pp. 217–237, 309–316.)

In a paper "On a Possible Origin of Petrosilicious Rocks" (Proc. Bost. Soc. Nat. Hist., 1879, XX., pp. 160–169), Mr. Crosby advocated the view that the felsites were of a deep-sea origin corresponding to the "red clay" of the Challenger Expedition. In this paper he remarks : —

"These rocks, which are widely distributed over the globe and compose formations of great extent, are undoubtedly of marine origin. We can scarcely regard them as shore deposits, and therefore it seems natural and legitimate to conclude that they were formed in the deep sea ; and I would submit that

they are very fairly represented by the modern abyssal accumulations, especially if we take into account the enormous period of time which has elapsed since their formation, and the probable changes in the physics and chemistry of the sea which it has wrought. The petrosilicious rocks are often distinctly and beautifully banded. This structure usually results from the alternation of very thin and regular quartzose and feldspathic layers, and although doubtless originating in, and determined in direction by, the sedimentary process, I think it can be proved that it has been made much sharper and more definite by a subsequent partial segregation of the ingredients, especially the Silica."

Dr. Wadsworth, from examinations of the felsites in the field and under the microscope, became convinced, in 1878, that their characters were the same, excepting in their alteration, as those of the volcanic rhyolites so common in the Cordilleras, the banding being a fluidal structure. He convinced himself that we had here the remains of ancient volcanic action, shown by ashes and other ejected fragmental material, lava flows, dikes, etc., such as at the present day accompany eruptive action. Subsequently the whole series had been more or less altered by various agencies. While in some places a recomposed conglomerate was found made up of water-worn detritus resting on the parent felsite, the structure as a whole was unlike that described by Messrs. Hyatt and Hunt.

Dr. Wadsworth found that in many cases there had first been thrown out a rhyolitic ash, and that through, around, and over this ash the rhyolitic lava has been poured, — the structure being identical with that observable in the more recent lava flows of the West. No passage could be traced between the fragmental and non-fragmental forms, but distinct lines separating the two could be found on careful observation.

Dr. Wadsworth also ascertained that two or more distinct flows had taken place at Marblehead Neck, and that the felsite also cut the granite in dikes of various dimensions. The opposite view had been taught by Messrs. Hunt and Crosby, but their evidence was taken from some felsite dikes cutting the granite near the boundaries of the main masses of these rocks, where only the most careful examination would show which was the intrusive one. Dr. Wadsworth's statement was based on finding smaller dikes of felsite, which gradually narrow and come to an end in the granite and on felsite dikes which hold fragments torn from their granite walls. He has examined the relations of the two rocks over much of the coast, and has always found the same relation between them.

As a result of microscopic investigations the banding was found to be

a fluidal structure, and not due to a linear arrangement of the quartz and feldspar, as had been supposed by some. The base of the felsite has become devitrified, as is seen to have been the case, to a less extent perhaps, in many modern rhyolites. The grains and crystals in the groundmass extend from one band to another, and do not have a stratified arrangement. Dr. Wadsworth's conclusions were published in 1879, in the Bulletin of this Museum (V., pp. 275–287).

Dr. Wadsworth, not being able to find the time necessary for a thorough examination of the felsites in the vicinity of Boston, with a view to a complete elucidation of the question whether these rocks were of sedimentary or of eruptive origin, called for assistance on one of his pupils, Mr. J. S. Diller, assigning to him, as a subject for a thesis,* the felsites and the associated rocks in a district selected as being suitable for throwing light on the question at issue, and also because it was one in which Dr. Wadsworth himself had done but little work, so that the pupil would not feel in any way hampered by conclusions previously reached by his teachers. All that was asked of Mr. Diller was to observe the facts carefully, and give the conclusions to which they led, let the results be what they would.

Mr. Diller's work gradually expanded, until he took in finally almost all of the felsitic area north of Boston. He made a detailed map of the region examined, and published his results in the Proceedings of the Boston Society of Natural History; and again, when further extended, in the Bulletin of this Museum. Mr. Diller showed in the district studied by him that a series of stratified rocks occurred, which he regarded as the oldest rocks observed. These were intersected by distinctly eruptive granite, and this again by felsite. All were again cut through and through by successive eruptions of basaltic rocks.

He concludes that there is no true felsite belonging to the stratified group, the quartzite and slates being wholly distinct from the felsites both in structure and origin. It will be remembered that Mr. Crosby stated that, on going northward in Mr. Diller's district, the porphyritic character of the felsite gradually disappeared, the latter becoming interstratified with quartzite and hornblende slates. It was said that the transition was so gradual that no boundary line could be drawn between the stratified and unstratified portions, thus proving that there was no break and no natural division here.

* Mr. Diller was at that time (1880–81) a candidate for the degree of S. B. in Harvard University. Later he was appointed Geologist to the Assos Expedition, and is now in the employ of the U. S. Geological Survey.

Mr. Diller, on the other hand, showed that the felsites were not exposed within some eight hundred and fifty feet of the stratified rocks, and that when last seen they were as porphyritic as at any other point. The accuracy of his work has not been impeached by any one; nor is it easy to see how his conclusions can fail of acceptance on the part of those familiar with the lithological characters of eruptive rocks.

Mr. Diller found the granite breaking through and holding fragments of the stratified rocks. The felsite was seen always to cut the granite, but the reverse could not be found. Splinters in curved and crescent-shaped forms were found in the rhyolitic (felsitic) ash, and in their forms were identical with those so commonly occurring in the rhyolitic ashes of the West. These forms, as would naturally occur in such old glasses, were replaced by silicious material, forming pseudomorphs. The microscopic characters thus sustained the relations indicated by the work in the field. Mr. Diller clearly showed that, while part of the ashy material was earlier than one felsite at least, since it was cut by dikes of it, it had been in part worked over by water and stratified. This water-deposited ash passed into conglomerate and sandstone in places, as is natural in any detrital material having that origin. The ash when consolidated closely resembled the parent rock, and led many observers to think that here the transition between sedimentary rocks and true felsites occurred. (Proc. Bost. Soc. Nat. Hist., 1880, XX., pp. 355–368; Bull. Mus. Comp. Zoöl., 1881, VII., pp. 165–180.)

The present writers examined from time to time, in company with Mr. Diller, parts of the region he was engaged in investigating, as well as his microscopic sections, and are thus able from personal knowledge to testify to the accuracy of his work. In our opinion, there can be no doubt that the felsitic rocks of Eastern Massachusetts show all the characters that a modern volcanic rhyolitic district would, if situated on a sea-shore, and afterwards subjected to the ordinary denuding and metamorphic agencies. In places, in the field, there can be but little difference perceived between the modern and ancient forms.

In his Contributions to the Geology of Eastern Massachusetts, 1880, on account of some objections made by Dr. Hunt, Mr. Crosby called the Norian series of his former paper, the "Naugus Head series." The account of its generally eruptive character is given nearly as before, and is as follows (pp. 18–22): —

"That this series of pyroxenic and feldspathic rocks, with its associated minerals, — which is sometimes stratified, oftener eruptive, frequently very coarsely crystalline, and always quartzless, — is distinct from anything ob-

served elsewhere in Massachusetts, cannot be doubted. Lithologically at least it may be said to be *sui generis* in Massachusetts geology. The great disturbance which the Naugus Head series everywhere exhibits, and its thoroughly crystalline appearance, stamp it as older than the Huronian and Montalban formations. . . . . What, now, are the geognostical relations of the Naugus Head series to these Huronian terranes? It underlies them. Everywhere, along the boundaries of the Naugus Head areas, we find the various members of this series penetrating and cutting through the Huronian rocks. But the converse of this is never observed. Nowhere, so far as my observations extend, does the Naugus Head series appear to be cut by the adjoining Huronian rocks; nor by any member of the Huronian system; nor, in fact, by any rocks not easily referable, as already stated, to the stratified portions of this series itself. In short, the Naugus Head series appears to be, as it were, at the bottom; and, while it has been extravasated extensively through superjacent formations, it is penetrated by nothing foreign to itself. . . . . The Naugus Head series is certainly distinct from, and . . . . probably underlies, the Huronian; and, since it bears no likeness to the Laurentian system, we are brought to the conclusion, that, if it is to be correlated with any series already described, that series is the Norian. In short, the Naugus Head series does not resemble the Laurentian, and is, stratigraphically, where we should expect to find the Norian. . . . . The only rocks in Massachusetts that have been observed passing below the Huronian system, or cutting through its lower members, are those composing the Naugus Head series; and this, together with its crystalline character and immense disturbance, convinces me that this series is the oldest in the State. In the light of our present knowledge the conclusion cannot be avoided, that the Naugus Head series is the real base of the geological column of Massachusetts."

An examination of this so-called Norian or Naugus Head region and its rocks, by Dr. Wadsworth, has shown that the chief rock is of similar character to the zircon syenite of Norway, and that it consists principally of orthoclase, with hornblende and some microcline and plagioclase, together with microscopic and macroscopic zircons. The feldspar has the same inclusions as that of Norway. At Naugus Head a dark micaceous schistose rock occurs. Through this schist the syenite has been erupted, forming long bands parallel with the foliation. These bands vary from a fraction of an inch to many feet in thickness. This structure strikingly resembles stratification, and has been taken as such; but, if a careful examination is made, it will be seen that the syenite follows the foliation only approximately, and that after running some distance it suddenly shoots across the foliation into other bands. Fragments of the schist are abundantly enclosed in the syenite, while dikes of the latter can be seen cutting directly across the schist.

At this locality, and elsewhere about the harbor, the syenite can be seen cutting irregularly through the schist in every direction, thus forming with it a network of fragments. Such also is the case with the granite along the seaward shore of Marblehead, both north and south of the Neck. The breaking of the syenite across the foliation, the interlocking of its bands, its included fragments of schist, its irregular network structure as well as its cross dikes, and the fact that, like the granite, it sometimes covers large areas alone, — all this proves that it is an eruptive rock of later date than the schist, and not interstratified with it. Furthermore, it was observed that the "Naugus Head Series" was cut both by granite and felsite, and that the statements to the contrary were incorrect. In addition to the syenite numerous dikes of diabase occur of different periods, probably separated by long intervals of time. (Proc. Bost. Soc. Nat. Hist., 1881, XXI., p. 294, Feb. 1, 1882; Harvard Univ. Bull., 1882, II., p. 359.)

Of the Huronian system Mr. Crosby remarks (Contributions, pp. 26, 27, 34, 36, 37, 38, 43, 45): —

"The Huronian system in this region, like the Naugus Head series, though in a somewhat less degree, exhibits great disturbance. Distinctly bedded rocks are the exception; and, although many apparently structureless rocks are probably really stratified, it is undoubtedly true that a large part, perhaps the greater part, of the formation has been more or less fluent, and extravasation may be set down as a characteristic structural feature. . . . . The Huronian series of Eastern Massachusetts is principally composed of the following rocks, or, rather, groups of rocks: —

1. Granite (hornblendic and binary).
2. Petrosilex (passing into felsite and quartzite).
3. Diorite (unstratified and largely exotic).
4. Hornblendic Gneiss, Stratified Diorite, etc.
5. Limestone.

"Although so connected lithologically and stratigraphically as to be clearly members of one great series, yet these various groups are, on the whole, well separated, occurring mainly in large masses. The stratigraphic distinctness would be much more striking but for the wide-spread extravasation which some of the divisions have experienced. . . . . The true sequence, excluding some of the limestone, is expressed in the foregoing classification.

"The Huronian granites of this region sometimes exhibit traces of stratification. Many examples of well-marked bedding have probably escaped observation; and there can be little doubt that the granites in some cases really possess a gneissic structure where the rock is too coarse and massive to enable the eye to detect it. Yet I do not hesitate to assert that such phenomena must, wherever occurring, be very local; for it can be proved beyond a doubt

that the Huronian granites of this region are mainly exotic. We have seldom far to look to find, in the form of enclosed, angular fragments of clearly-stratified rocks, evidence of their extravasation; and near the boundaries of the granites we often observe them cutting the adjoining rocks, especially if these are stratified, in a manner incompatible with any theory that would regard them, in their present condition, as chiefly indigenous. . . . . Believing with Prof. Shaler, and also with Mr. T. T. Bouvé, that all these granites are metamorphosed sediments, I conceive that the peculiar planes of separation (joint structure) referred to by Prof. Shaler demand a different interpretation from that proposed by him, for evidence is not wanting of the extravasation of the granite at many points along the Blue Hill or Quincy and Milton range. . . . . It is well known that the Quincy granite is met along its northern border by conglomerate and slate. . . . . The actual contact of this rock with the granite is displayed, however, at a place about ½ mile west of the Old Colony R. R. . . . . The contact line is extremely irregular; and the relation of the granite to the semi-crystalline rock is unquestionably that of an exotic. Some three miles to the southwest, it is very distinctly cut by dykes and irregular strings of the underlying and surrounding granite. According to Prof. W. H. Niles, the relations of the granite and slate on Weymouth Fore River, near the trilobite quarry, affords equally conclusive evidence that at least a portion of the granite has experienced some extravasation since the deposition of the slate. The slates on the South Shore R. R., immediately east of the station at Weymouth Landing, are in contact with the granite, which cuts through, and overlies them in a manner possible, apparently only with an exotic; and at the contact of the granite and slate, southwest of the station, Prof. Niles has observed angular fragments of slate actually enclosed in the granite, though lying only a few inches from their original positions in the parent bed. The induration, as if by heat, of the slate and conglomerate at most points where they adjoin the granite, and the frequent development of amygdaloidal characters in the slate in those places, are also facts which tell strongly in favor of the former igneous condition of the granite. The evidence of the extravasation of the granite afforded by a study of its relations to the uncrystalline rocks appears to be sufficiently conclusive as regards the portions of granite immediately involved. . . . . At Hospital Point on the Beverly shore, near the water's edge south of the lighthouse, is a considerable mass of distinct mica-slate enclosed in the coarse, structureless granite. A smaller mass of a similar stratified schist is enclosed in the granite near the northern end of the railroad-cut in Beverly. On Marblehead Neck the relations of the granite to the fine-grained, distinctly stratified schist occurring there, are such as to leave no doubt that the granite is exotic. Along the shore, at the southwestern end of the neck, the exposures are magnificent, and one can see, especially at low tide, numerous angular, ragged, contorted masses of the schist, of various sizes, enveloped by the granite. . . . . It has been set down by all observers as the oldest rock in this region, and this view is abundantly justified (except as regards the Naugus Head series), not only by its generally

coarsely crystalline aspect and the great disturbance and almost complete absence of stratification which it everywhere exhibits, but also by the general fact that it cuts, as an exotic, all the other members of the Huronian system. In fact it pierces, in its well-nigh universal extravasation, every rock in this region, save the Naugus Head series and the newer unerystallines. In its geographical distribution we have a strong indication that the granite belongs to the Huronian system; for it is co-extensive with that system, and does not occur beyond its limits. And it will be shown farther on that its lithological relations point indubitably to the same conclusion. But its petrology makes it clear that, if the granite is referred to the Huronian series, it must be regarded as the lowest, and hence the oldest member of that series. It appears, in fact, to be the foundation of the Huronian system in Massachusetts. . . . . Although well satisfied that a large proportion of the granite has been in a state of igneous plasticity, yet its relations to the stratified petrosilex and the many traces of bedding which it still retains forbid me to believe that the mass of this rock has been elevated from any vast depth; it seems rather like an extensive stratified formation which has been softened *in situ*, and then to a greater or less extent forced out of its normal position by the pressure of surrounding and overlying terranes."

Mr. Crosby now classed nearly all of the felsite under that obsolete term petrosilex, following in this, as in almost all of his work, the ideas of Dr. Hunt. Of the felsite and its relations to other rocks he says (*l. c.*, pp. 47–69):—

"The petrosilex of this region is overlaid at many points by a group of rocks, including the well-known petrosilex breccia, which appear to be in every case merely the more or less thoroughly reconsolidated mechanical débris of petrosilex itself. This second group of petrosilicious rocks constitutes one member or division of a formation much newer than the Huronian, for which I have proposed, provisionally, the name Shawmut group: a semi-crystalline series which, as will appear in the sequel, underlies the primordial slate and conglomerate of Eastern Massachusetts, coming between these oldest Paleozoic sediments and the Huronian beds, and appearing to have been formed toward the close of Eozoic time. The petrosilicious portion of the Shawmut group includes rocks of all textures, from a coarse breccia to a compact, homogeneous rock which the naked eye cannot distinguish from the parent petrosilex. They are proved to be of more recent origin than the Huronian petrosilex, not only by their petrological relations, since they everywhere overlie the Huronian, but also and most conclusively by the fact, already stated, that they are composed mainly of the débris of petrosilex, which, where the material is coarse, can be plainly seen to be identical with that which may be referred with certainty to the Huronian system. . . . . That the Huronian petrosilex is now for the most part a stratified rock, and was originally wholly so, I cannot doubt; and it appears most probable that the conditions presiding over its

deposition differed in degree only, if at all, from those that have obtained in more recent geological times. . . . . So far as I am aware, those limited portions of the Huronian petrosilex containing distinctly marked pebbles occur chiefly in the immediate vicinity of the petrosilex breccia of the Shawmut group; and in nearly every instance the evidence is plain that the petrosilex has experienced some extravasation, and has, consequently, been in a more or less fluent state. . . . . On the eastern shore of Marblehead Neck . . . . the former reposes directly upon the latter; and both series have evidently suffered great disturbance. The light-colored Shawmut breccia is cut and torn in every direction by tortuous dykes of the black petrosilex, which itself very clearly holds angular pebbles of different varieties of petrosilex. . . . . The main point to be proved in this connection is brought out at this locality with especial clearness; viz., that the very same petrosilex which holds pebbles underlies, and is in part eruptive through, the breccia, forcing the conclusion that, in spite of a certain superficial resemblance, these are distinct formations. . . . . To summarize, the facts observable at the places named, and elsewhere, compel us to suppose that the petrosilex, while suffering great disturbance, has been locally crushed and brecciated, and that certain portions of this rock, perhaps as a consequence of enormous friction, have been softened to an extent that would permit the envelopment of extraneous masses. . . . . The theory of the conglomerate origin of the banded petrosilex . . . . is I think based upon an entire misapprehension of the principal facts."

He admits the extravasation of the felsite through the brecciated material or ash, and states that the evidence that the banding was formed by flattened pebbles "is wholly illusory." (*l. c.*, p. 68.)

He claims that in Melrose is a locality that

"places beyond question the fact that there is a gradual transition between the quartzite and petrosilex, and that portions of the latter rock are intercalated in the stratified group." (*l. c.*, p. 106.)

This locality, however, was, as already mentioned, studied by Mr. Diller, and nothing of the kind found there. Dr. Wadsworth also examined the rocks in place at that locality, and found no felsite or any other rock that ought to be mistaken for a felsite.

Mr. Crosby further states: —

"The conclusion is now certainly safe that the eruptive diorites and the stratified group are unequally metamorphosed portions of one great series of basic rocks." (*l. c.*, p. 112.)

But this, like his other conclusions, rests on his inability to distinguish between different rocks, and is purely theoretical.

In 1879 Prof. N. S. Shaler took the ground that the shales and conglomerates of Roxbury passed into the amygdaloidal melaphyr, locally

known as the Brighton amygdaloid. He held that a "trained eye" could trace the gradual passage from the conglomerate to the melaphyr, remarking as follows: —

"We see . . . . a mass of conglomerate essentially the same as the Roxbury pudding stone, only the pebbles and the cement have been greatly affected by heat, so that the whole is more fused together than in the ordinary forms of that conglomerate — looking closely we see that the matrix of the pebbles and to a certain extent the outer parts of the pebbles themselves are filled with cavities in which similar amygdules have been formed. With care and with favorable conditions of the quarries, the observer may trace the stages of this transition, from the faintest beginning of this structure in rocks which are distinctly conglomerates, into rocks where the blebs have been so completely developed that every trace of the original pebbly structure is now lost, and the mass converted into the amygdaloidal trap." (Proc. Bost. Soc. Nat. Hist., 1879, XX., pp. 129–133.)

From this he argued that the Roxbury conglomerate had been deeply buried under sedimentary deposits, forming lofty mountains, which had since been worn away to their foundations, the conglomerate in the mean time undergoing fusion, and being thus converted into melaphyr.

Later, the question of the nature of the Brighton melaphyr (amygdaloid) was taken up by Prof. E. R. Benton, who showed that the amygdaloid was a melaphyr or an old altered basalt, which owed its present variation from basalt to changes subsequent to its original formation. The structure he regarded as pseudo-amygdaloid, and the supposed pebbles and fragments were shown to be the same as the remaining portion of the melaphyr. He also points to the fact that Professor Shaler's hypothesis requires the heterogeneous pebbles of the conglomerate to be transformed into the homogeneous ones of the melaphyr; also, that no part of the melaphyr is like the Roxbury conglomerate. Professor Benton further showed that all the claims made in the past, that the melaphyr passed into slates, conglomerates, etc., were without any basis of fact, for a distinct line of separation between these rocks could be found whenever they were seen together. (Proc. Bost. Soc. Nat. Hist., 1880, XX., pp. 416–426.)

Associated with the general belief in the production of crystalline and eruptive rocks by the fusion of sediments is the theory of the plasticity of pebbles in conglomerates, a theory at least as old as the days of Michael Kirwan. Certain forms observed in Brighton were regarded by Mr. Crosby as the result of the compression of the quartzite pebbles in a plastic state, but on examining the district in question Dr. Wadsworth found that these forms were confined to glaciated surfaces, and

were not met with elsewhere in the conglomerate. Some of the indentations were much deeper than they were broad, and hence could not have been formed by the pressure of one rounded pebble upon another. Mr. Crosby claimed that certain fissuring in the pebbles occurred during the time of the compression; but these fissures were found to be filled with vein-crystals of quartz, which had suffered the same indentation as the pebble, so that it was impossible for both to have been formed at the same time. The forms in question were attributed by Dr. Wadsworth to glaciation, the rock being found to be smoothed on both its north and south sides as well as in its depressions; while sand action later appeared to have given rise to some of the peculiar forms observed, either directly or by the modification of previously existing surfaces. It was also pointed out by him that some pebbles had indeed been compressed and indented; but that the forms exhibited in such cases were different from the peculiar ones under discussion; the indentations, fractures, etc. being such as would naturally take place when a fragmental rock like quartzite was subjected to compression. It was furthermore remarked, that no softening and plasticity could have occurred, because the grains of quartz were round and intact, and not flattened, as Mr. Crosby's view demanded.

This subject of plasticity of the conglomerate pebbles was again under discussion before the Boston Society of Natural History, Mr. Crosby claiming that he found compressed forms below the original surface, and attempting to explain them by saying that they were due to a lack of cohesion amongst the sand grains in the quartzite. This ground had, however, been already taken by Dr. Wadsworth for certain forms observed; and it will be noticed that it begs entirely the question of the softening and plasticity claimed. A rock that has been softened by metamorphic agencies, so as to have become plastic, must be so throughout its entire mass. Mr. Crosby's view was similar to that which would be taken in regard to sand, if it were to be said that it ran through a hole by virtue of its plasticity.

Mr. Crosby also tried to show that the pebbles of the Bellingham conglomerate had been squeezed or pulled out into spindle-shaped masses; but it was evident to more than one who examined his specimens, that he had confounded the adhering matrix with the pebbles themselves, — a not uncommon mistake. (Proc. Bost. Soc. Nat. Hist., 1879–80, XX., pp. 308–318, 368–378, 405.)

Mr. W. W. Dodge gave, in 1881, a paper containing numerous details of his observations in the vicinity of Boston. In this paper he noticed

the occurrence of felsite dikes in the granite, as had been previously indicated by Dr. Wadsworth and Mr. Diller. (Proc. Bost. Soc. Nat. Hist., 1881, XXI., pp. 197–216.)

In 1881 Dr. Wadsworth showed that the rock which Mr. Crosby had regarded as slate or sandstone on Marblehead Neck was really a lava flow, — a trachyte; and hence it appeared that the theory of the latter regarding the filling of Marblehead Harbor by sandstone, and its subsequent erosion, was based on an error regarding the nature of the rock in question. (Ibid., pp. 288–294.)

Dr. Wadsworth also showed that the so-called diorite or syenite of Marblehead was a diabase. (Ibid., p. 306.)

It was later pointed out that a supposed felsite on Central Avenue, Milton, from the detritus of which the associated conglomerate was believed by Mr. Crosby to have been formed, was simply a modified portion of the conglomerate itself, and that here as elsewhere the usual mistakes regarding the character of the rocks had been made. (Bull. Harv. Univ., 1882, II., pp. 431, 432.)

In a paper presented to the Boston Society of Natural History in 1883, it was pointed out by Dr. Wadsworth that the Roxbury conglomerate unconformably overlaid the argillite, and contained fragments of the latter. The argillite showed an old eroded surface, with its strata cut off; while abutting against the laminæ was the conglomerate that had been deposited on this surface. Mr. Crosby had held that the conglomerate lay beneath the argillite, and explained the appearance at the locality in question by supposing the existence of a closely folded synclinal; but the evidence that the conglomerate is really unconformably laid down on the older argillite and contains its *débris*, Dr. Wadsworth thinks, must be patent to any one who carefully examines the locality. No faulting exists, for the two rocks are so closely adherent that both can be removed as a single piece, which distinctly shows the unconformability. It was further shown that an argillite occurred interbedded with the conglomerate, and that a conglomerate of a later date than the Quincy granite had been found on the northern side of that rock. The argillite beneath the conglomerate in the Boston Basin is a fine-grained compact rock, while that associated with the conglomerate is coarse-grained arenaceous, passing into sandstone and conglomerate. To the former belong the Newton, and probably the Braintree argillites; while to the latter is provisionally referred the misnamed Cambridge slates.

In 1883 Mr. W. W. Dodge claimed that two granites existed in the Quincy district, the outer being older than the inner one, but he gave

no evidence in support of this view. (Amer. Jour. Sci., 1883, (3) XXV., pp. 65–71.)

Dr. Wadsworth showed, in 1881, that the Quincy granite was intrusive in the fossiliferous argillite, and that the supposed sandstone and quartzite of Professor Shaler — the felsite (orthophyre) of Dr. Hunt — was simply the granite modified by its contact with the argillite. No faulting existed, for the two rocks were welded into a solid mass. He also pointed out that the dip of the argillite was southerly, instead of northerly, as had been claimed by Messrs. Rogers, Jackson, and Shaler. (Proc. Bost. Soc. Nat. Hist., 1881, XXI., pp. 274–277.)

VERMONT AND WESTERN MASSACHUSETTS.

The geology of Eastern Massachusetts presents us, as has been seen in the preceding pages, with a complication of problems, toward the solution of which but little progress was made by the earlier investigators. A similar condition of things is revealed when we examine what has been published in regard to the age and sequence of the formations in the western portion of the State. Of what was known on this subject at the time of the publication of President Hitchcock's Final Report on the Geology of Massachusetts (1841), a good idea may be formed from the following quotation from that work in regard to the age of the limestone of Berkshire County : —

"According to the views which have now been suggested, it will follow, that wherever we find the limestone of Berkshire county enclosed between strata of gneiss, it must be regarded as the oldest variety of that rock, or primary limestone. Where it is interstratified with mica and talcose slate, although more recent than in gneiss, it ought still probably to be regarded as primary. But when we find it above these rocks ; . . . . then as it lies immediately beneath clay slate, it may be what is called primary, or what is called transition, according as we place clay slate on the one class or the other." (Final Report on the Geology of Massachusetts, p. 581.)

Prof. H. D. Rogers, in 1856, in his sketch of the geology of the United States, furnished for publication in Johnston's Physical Atlas, makes two periods below the "Cambrian or Older Silurian"; one, the "Azoic or Semi-Metamorphic"; the other, the "Hypozoic, or True Metamorphic." The basis on which this classification rests seems to be

a purely imaginative one. As an illustration of the correctness of this statement, it may be mentioned that the Coast Ranges and the Sierra Nevada of California are placed in the Azoic by Professor Rogers. At that time nothing had been ascertained in regard to the geological age of these chains; but they are now known to be made up of rocks not older than the Carboniferous, the Coast Ranges in fact being of Cretaceous and Tertiary age, with associated eruptive and intrusive matter.

Professor Rogers states that the "Azoic sediments" were succeeded by those of Palæozoic age, "in some quarters apparently with, in some without, the interruption of a disturbance of levels." The merging of the Azoic with the Metamorphic Palæozoic under one color on the map was said to have been

"made indispensable by the absolute impossibility of ascertaining at present the true base of the Palæozoic system, for the history of Geology forbids us to believe that research has yet detected the actual horizon of the dawn of animal and vegetable life upon our globe."

Professor Rogers, at that time, seems to have known little or nothing of what had been done toward developing the geological structure of the country, either by the Lake Superior Survey, or by that of Canada. Neither was there any other than a purely theoretical basis for his division of the rocks below the Lower Silurian or Cambrian into a "semi-metamorphic" and a "true metamorphic" system.

The work of the Canada Geological Survey on the borders of Vermont — from which in a northeastern direction the rocks become less and less difficult to decipher, because their relations are less obscured by metamorphism — could not fail, if it were well done, to be of great assistance in unravelling the intricacies of New England geology.

In 1849 the first published statement appears to have been made of the results obtained by that Survey, bearing especially on the question of the continuity through New England of the Canadian formations. This statement was made by Dr. Hunt, "of the Geological Commission of Canada," and was said to be "a brief sketch of the results obtained by Mr. Logan and his associates." It reads as follows: —

"The facts which we have stated seem to show that the sandstones and red slates with their chromiferous chloritic bands, are identical with the dolomitic, chloritic and quartzose rocks of Sutton valley, and these with the serpentines and quartzose rocks of the valley of the Missisquoi; so that the whole of the Green Mountain rocks, including those containing the auriferous quartz veins, belong to the Hudson River group, with the possible addition of a part of the Shawangunk conglomerates. The fossiliferous rocks of the St. Francis valley

are evidently Upper Silurian and referable to the Niagara limestones; a similar formation has been met with at Gaspé and traced one hundred and fifty miles S. W.; and from the similarity of the Notre Dame to the Green Mountains and the fact that the Hudson River rocks are continuous along the St. Lawrence to Cape Rosier, we may conclude that the Upper Silurian rocks will be found continuous, or nearly so, throughout. They constitute the calcareo-micaceous formation of Prof. Adams, which he has traced nearly to the southern line of Vermont. Resting upon this formation in Gaspé is a body of arenaceous rocks, seven thousand feet thick, which apparently correspond to the Chemung and Portage group of New York, with the old red sandstones. As this formation is found extending quite to the Mississippi, it is probable that it will accompany the Silurian rocks through New England and surround the coal fields of New Brunswick, of Eastern Massachusetts and Rhode Island. To this may perhaps be referred in part the rocks of the White Mountains, which may sweep around the Western border of the Massachusetts anthracite formation until lost under the super-carboniferous rocks of the Connecticut River. The limestones of Western New England seem to be no other than the metamorphic Trenton limestones of Phillipsburg, while the chlorito-epidotic rocks and serpentines of Sutton valley appear again in the rocks of Southern Connecticut between these limestones and the new red sandstone. With such a key to the structure of the metamorphic rocks of New England and of the great Appalachian chain of which these form a part, we may regard the difficulties that have long environed the subject as in a great degree removed, and the bold conjectures as to their metamorphic origin which have been from time to time put forth, fully vindicated." (Am. Jour. Sci., 1850, (2) IX., p. 19; Proc. Am. Assoc. Adv. Sci., 1849, II., pp. 333, 334.)

In 1850 Dr. Hunt again expressed similar views with regard to the age of the Green Mountain rocks. (Proc. Am. Assoc. Adv. Sci., 1850, IV., pp. 202–204.) He declared that the view of Professor Emmons, that the Taconic system was older than the Silurian formation, was at variance with the structure of the region, as deduced both from stratigraphical and geographical analogies. After summing up the observations which, according to him, were in absolute contradiction with the theory of the pre-Silurian age of the so-called Taconic rocks, he remarks: —

"Such are the facts that lead to the conclusion that between the crystalline rocks of the East side of Lake Champlain and the North shore of the St. Lawrence, on the one hand, and the Upper Silurian limestones at the eastern base of the Green Mountain range on the other, there are no rocks more ancient than the Silurian."

Again, in 1854, Dr. Hunt referred the crystalline limestones of Western New England, and their continuation through Northeastern New York and the adjacent parts of New Jersey and Pennsylvania, to the

Lower Silurian, citing Mather's opinion to the same effect. (Am. Jour. Sci., (2) XVIII., pp. 195–198.)

In 1861 Dr. Hunt once more stated his opinion very fully with regard to the relations of the formations of the Appalachian chain to those studied out in Canada by the Geological Survey. He closed with the following statement : —

"It will be seen from what has been previously said that we look upon the 1st and 2d divisions described by Mr. Safford in Eastern Tennessee, as corresponding to the hypozoic series of Rogers and to the Green mountain gneissic formation, which instead of being beneath the Silurian series, is really a portion of the Quebec group more or less metamorphosed, so that we recognize nothing in New England or southeastern Canada lower than the Silurian system, nor do we at present see any evidence of older strata, such as Laurentian or Huronian, in any part of the Appalachian chain. The general conclusions which we have previously expressed with regard to the lithological, chemical and mineral relations of the Green mountain rocks remain unchanged. (This Journal [2], IX, 12)." (Am. Jour. Sci., 1861, (2) XXXI., pp. 392–414.)

In the Geology of Canada, 1863, the Green Mountains of Vermont were still regarded as belonging to the Quebec group, as above given in the preceding papers, and as being of Lower Silurian age. (See also Am. Jour. Sci., 1863, (2) XXXVI., pp. 214–226.)

In the Geology of Canada, 1866, Dr. Hunt stated : —

"Between the Potsdam and Chazy periods, a rapid continental elevation, and subsequent gradual depression, allowed a great accumulation of deposits, which now appear in the rocks of the Green Mountain range. . . . . To this [the Upper Calciferous] succeeds the Quebec group, which is regarded as occupying a position in the series between the Calciferous and Chazy formations. The members inferior to it have not yet been observed in eastern Canada, nor, with the exception of the Potsdam of St. Albans and Georgia in Vermont . . . . The Quebec group constitutes the great metalliferous region of eastern Canada, Vermont and Newfoundland ; and the Upper Copper-bearing series of Lake Superior, in which the principal mines of that region are found, belongs to the same geological horizon." (*l. c.*, pp. 235–237.)

In 1867 Dr. Hunt said that the Quebec group formed the Appalachian region of Canada and Vermont, as well as the metalliferous terranes of Lake Superior. He then considered the Quebec group as being the equivalent of the Landeilo, and occupying a position between the Upper Calciferous and Chazy. He further remarked that this group formed the Notre-Dame Mountains in Canada, and the Green Mountains in Vermont, and that it played a very important *rôle* throughout the Appalachian chain. (Esquisse Géologique du Canada, pp. 5, 6, 12–16.)

The same year Dr. Hunt further stated that the Quebec group had been proved, stratigraphically and palæontologically, to have been deposited between the Calciferous and Chazy. Also, that this group formed that part of the Appalachian region of Canada and Vermont occupied by the Green Mountains and their prolongation to the south. (Bull. Soc. Géol. de France, 1867, (2) XXIV., pp. 666, 667.)

Again, the Taconic Mountains and the Green Mountains were said to be portions of the Lower Silurian, which had escaped erosion; while the White Mountains of New Hampshire were said to be a detached portion of the Devonian formation, the Devonian sediments having been altered to gneiss and crystalline schists. (*l. c.*, p. 687.)

In 1869 Dr. Hunt remarked: —

"If we look at the North American continent, we find along its north-eastern portion evidence of great subsidence, and an accumulation of not less than 40,000 feet of sediment along the line of the Appalachians from the Gulf of St. Lawrence southwards, during the paleozoic period, and chiefly, it would appear, during its earlier and later portions. . . . . The region of Lake Superior, where we find the early portion of the paleozoic age marked by a great accumulation of sediments, comparable to that occurring at the same time in the region of New England, and followed or accompanied by similar plutonic phenomena." (Canadian Naturalist, 1869, (2) IV., pp. 395, 396; Smithsonian Report, 1869, p. 206.)

Still later Dr. Hunt made the following statement (Am. Jour. Sci., 1868, (2) XLVI., p. 229): —

"To sum up in a few words — all the evidence, paleontological and stratigraphical, as yet brought forward, affords no proof of the existence in Vermont of any strata (a small spur of Laurentian excepted) lower than the Potsdam formation, which the present advocates of the Taconic system regard as forming its summit. The supposed more ancient Middle and Lower Taconic clearly consists in part of Potsdam, in part of Utica and Hudson River, and in part of the Quebec group, which also constitutes the Lower Taconic. To the upper portion of the Quebec group, the Geological Survey of Canada have already referred the gneiss of the Green mountains, assigning to this chain a synclinal structure, nor does there yet seem to be any reason to believe otherwise. That strata still older than the Potsdam of New York and Vermont were deposited in some portions of the oceanic area, is apparent from the existence in New Brunswick of the St. John's slates holding a primordial fauna older than the Potsdam, and it is not impossible that their equivalents may underlie the Potsdam of Vermont. No such rocks have, however, as yet, been detected either in Vermont or Canada, and to preserve the name of the Taconic system as the designation of a series of rocks older than the Potsdam and

lying unconformably beneath it, is simply to perpetuate an unfortunate mistake which I believe Dr. Emmons, if now living, would, with the paleontological evidence at present before the world, be the first to acknowledge."

In 1870 Dr. Hunt stated regarding the Taconic rocks in Western Vermont and Massachusetts, that "the evidence up to this time adduced with regard to these so-called Taconic rocks, has failed to show that they include any strata more ancient than the Potsdam, while most of them are certainly younger." Of the Green and White Mountains he remarks in the same paper: —

"In fact, the schists and gneisses of the White Mountains are clearly distinct, lithologically, from the Laurentian, the Labradorian and the Huronian, as well as from the crystalline rocks of the Green Mountains, and from the fossiliferous Upper Silurian strata which lie at the southwestern base of the Canadian prolongation of the latter. Having thus exhausted the list of known sedimentary groups up to this horizon, it was evident that the crystalline strata of the White Mountains must be either (1) of Devonian age, or (2) something newer (which was highly improbable); or (3) must belong to a lower and hitherto unknown series." (Am. Jour. Sci., 1870, (2) L., pp. 83, 84.)

This language of Dr. Hunt, as well as other remarks in the same paper, is inexplicable, unless he still, as in the past, regarded the Green Mountain crystalline rocks as being Lower Silurian, and distinct from the Huronian.

The remarks of Dr. Hunt above quoted, beginning with the year 1863, possess an additional interest from the fact, to be shown later, that he claims that during all these years he held an entirely different opinion as regards the age of the Green Mountains, he, for official reasons, having been advocating views which he himself did not hold. It seems that later the official reasons became inoperative, for in the mean while Sir William Logan resigned his position as director of the Geological Survey of Canada, and Mr. A. R. C. Selwyn was appointed in his place.

It now appears from Dr. Hunt's various writings that some time between the date of the last quoted article, May 10, 1870, and October 19 of the same year, (he in the mean time having been appointed Professor of Geology in the Massachusetts Institute of Technology,) his views underwent a somewhat sudden "metamorphism." This showed itself in a marked manner, in 1871, in an address from which we proceed to quote, but it does not appear at first to have affected his general views of the Taconic system. The reasons for this change of opinion are nowhere given in any satisfactory manner.

In his Presidential Address before the American Association for the Advancement of Science in 1871, Dr. Hunt said: —

"The Taconic system as defined by him [Emmons] may be briefly described as a series of uncrystalline fossiliferous sediments, reposing unconformably on the crystalline schists of the Green Mountains, and partly made up of their ruins; while it is, at the same time overlaid unconformably by the Potsdam and calciferous formations of the Champlain, and constitutes the true base of the paleozoic column, — thus occupying the position of the British Cambrian. . . . . The objections made by Emmons to Rogers's view of the Champlain age of the Taconic rocks were threefold: first, the great differences in lithological characters, succession, and thickness, between these and the rocks of the Champlain division . . . .; second, the supposed unconformable infraposition of a fossiliferous series to the Potsdam; and third, the distinct fauna which the Taconic rocks were supposed to contain. The first of these is met by the fact now established that in the Appalachian region the Champlain division is represented by rocks having, with the same organic remains, very different lithological characters, and a thickness tenfold greater than in the typical Champlain region of Northern New York. The second objection has already been answered by showing that the rocks which, as in the St. Albans section, pass beneath the Potsdam, are really newer strata belonging to the upper part of the division, and contain a characteristic fossil of the Utica slate. As to the third point, it has also been met, so far as regards the Atops and Elliptocephalus, by showing these two genera to belong to the Potsdam formation. If we inquire further into the Taconic fauna, we find that the Stockbridge limestone (the Eolian limestone of Hitchcock), which was placed by Emmons near the base of the lower Taconic (while the Olenellus slates are near the summit of the Upper Taconic), is also fossiliferous, and contains, according to the determinations of Prof. Hall, species belonging to the genera Euomphalus, Zaphrentis, Stromatopora, Chaetetes, and Stictopora. Such a fauna would lead to the conclusion that these limestones, instead of being older, were really newer than the Olenellus beds, and that the apparent order of succession was, contrary to the supposition of Emmons, the true one. This conclusion was still further confirmed by the evidence obtained in 1868 by Mr. Billings, who found in that region a great number of characteristic species of the Levis formation, many of them in beds immediately above or below the white marbles, which latter, from the recent observations of the Rev. Augustus Wing, in the vicinity of Rutland, Vermont, would seem to be among the upper beds of the Potsdam formation. Thus while some of the Taconic fossils belong to the Potsdam and Utica formations, the greater number of them, derived from beds supposed to be low down in the system, are shown to be of the age of the Levis formation. There is, therefore, at present, no evidence of the existence, among the unaltered sedimentary rocks of the western base of the Appalachians in Canada or New England, of any strata more ancient than those of the Champlain division, to which, from

their organic remains, the fossiliferous Taconic rocks are shown to belong." (*l. c.*, pp. 22–24.)

Dr. Hunt further remarked in his Presidential Address : —

"The crystalline infra-Silurian strata, to which the name of the Huronian series has been given by the Geological Survey of Canada, have sometimes been called Cambrian, from their resemblance to certain rocks in Anglesea, which have been looked upon as altered Cambrian. . . . . The Anglesea rocks are a highly inclined and much contorted series of quartzose, micaceous, chloritic, and epidotic schists, with diorites, and dark-colored chromiferous serpentines, all of which, after a careful examination of them in the collections of the Geological Survey of Great Britain, appear to me identical with the rocks of the Green Mountain, or Huronian series. . . . . The gneissic series of the Green Mountains had, however, as we have seen, been, since 1841, regarded by the brothers Rogers, Mather, Hall, Hitchcock, Adams, Logan, myself, and others, as of Silurian age. Eaton and Emmons had alone claimed for it a pre-Cambrian age, until, in 1862, Macfarlane ventured to unite it with the Huronian system, and to identify both with the crystalline schists of similar age in Norway. Later observations in Michigan justify still farther this comparison. . . . . This view [that the White Mountain rocks were Upper Silurian and Devonian] adopted and enforced by me, was farther supported by Lesley in 1860, and has been generally accepted up to this time. In 1870, however, I ventured to question it, and in a published letter, addressed to Professor Dana, concluded, from a great number of facts, that there exists a system of crystalline schists, distinct from, and newer than, the Laurentian and Huronian, to which I gave the provisional name of Terranovan, constituting the third or White Mountain series." (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 26–28, 31, 33.)

We invite the reader's attention to the use of the term Green Mountain series as the equivalent of the Huronian, and to the statement that the White Mountain series is newer than the Huronian, hoping that he will remember it a short distance farther on.

Prof. J. D. Dana, in criticising Dr. Hunt's Address, remarked (Am. Jour. Sci., 1872, (3) III., pp. 92, 93) : —

"That he has relied, for his chronological arrangement of the crystalline rocks of New England and elsewhere, largely on lithological evidence, and commends this style of evidence ; — when such evidence means nothing until tested by thorough stratigraphical investigation. This evidence means something, or probably so, with respect to Laurentian rocks ; but it did not until the age of the rocks, in their relations to others, was first stratigraphically ascertained. It may turn out to be worth something as regards later rocks when the facts have been carefully tested by stratigraphy. A *fossil* is proved, by careful observation, to be restricted to the rocks of a certain period before it

is used — and then cautiously — for identifying equivalent beds. Has any one *proved* by careful observation that crystals of staurolite, cyanite, or andalusite, are restricted to rocks of a certain geological period? Assumptions and opinions, however strongly emphasized, are not proofs. It is no objection to stratigraphical evidence that it is difficult to obtain; is very doubtful on account of the difficulties; may take scores of years in New England to reach any safe conclusions. It must be obtained, whatever labor and care it costs, before the real order and relations of the rocks can be known. Until then, lithology may give us guesses, but nothing more substantial. Mr. Hunt's arguments with reference to the White Mountain Series, as urged by him in 1870, will be found in this journal, II, L, 83. Both there, and in his address, may be seen the kind of evidence with which he fortifies, or supplements, that based on the character of the rocks. Direct stratigraphical investigation over the region itself, in which all flexures, faults, and unconformabilities have been thoroughly investigated, is not among the foundations of opinion which he brings forward. He endeavors to set aside the objection to his views suggested by the existence of Devonian or Helderberg rocks in central and northern New England; but he presents, for this purpose, only some general considerations, of little weight, instead of definite facts as to the extent and variety of metamorphic strata that are part of, because conformable to, these Helderberg beds. Had he studied up these stratigraphical relations with the care requisite to obtain the truth, and all the truth, perhaps he would not longer say — it is 'contrary to my notions of the geological history of the continent to suppose that rocks of Devonian age could in that region have assumed such lithological characters.' Notions often lead astray." (See also Am. Jour. Sci., 1871, (3) II., pp. 205–207; 1872, IV., pp. 104, 105.)

In replying to Professor Dana, Dr. Hunt states (Amer. Jour. Sci., 1872, (3) IV., p. 51): —

"With regard to New England rocks, Prof. Dana asserts that 'there are gneisses, mica schists, and chloritic and talcoid schists in the Taconic series.' I have, however, shown in my address that Emmons, the author of the Taconic system, expressly excluded therefrom the crystalline rocks, which he included in an older primary system; excepting, however, certain micaceous and talcose beds, which he declared to be recomposed rocks, made up from the ruins of the primary schists, and distinguished from these by the absence of the characteristic crystalline minerals which belong to the Green Mountain primary schists. Again, Prof. Dana states that I make the crystalline schists of the White Mountains a newer series than the Green Mountain rocks. A careful perusal of my address will show that I nowhere assert that the rocks of the third series, on my line of section, are younger than the second series. Such a view of their relations has, however, been maintained for the last generation by the Messrs. Rogers, Logan, and many others, all of whom assigned the crystalline schists of the White Mountains to a higher geological horizon than the Green Mountains. . . . . My 'chronological arrangement' of

New England crystalline rocks, as it is called by Professor Dana, so far as it is my own, is limited to my affirmation that they are all of pre-Cambrian age. . . . . As regards the mica-schists with staurolite, cyanite, andalusite and garnet, I have in my address pointed out the fact that they appear to belong to a great series of rocks, very constant in character, which have a continuous outcrop from the Hudson River to the St. John, a distance of 500 miles, and, in the latter region are clearly pre-Cambrian. I have, moreover, brought together the evidence of observers in other parts of North America, in Great Britain, in continental Europe, and in Australia, showing that similar crystalline schists, holding these same minerals, always occupy, in these regions, a similar geological horizon. Prof. Dana hereupon inquires whether any one has yet *proved* that these mineral characters are restricted to rocks of a certain geological period. I answer, that in opposition to these facts, it has not yet been proved that they belong to any later geological period than the one already indicated; and that it is only by bringing together observations, as I have done, that we can ever hope to determine the geological value of these mineral fossils."

Regarding the existence of staurolite, etc., as a criterion of geological age, Dr. Hunt wrote, in 1878: —

"It is by a misconception that some have been led to regard the presence of staurolite, cyanite and andalusite, as exclusively characteristic of the Montalban, a proposition nowhere maintained by the writer, since, although they have not been found in the oldest terranes, these mineral species have long been known to occur, in many localities, in the Taconian schists." (Azoic Rocks, p. 211.)

We do not understand what Dr. Hunt did mean, in 1872, in his remarks given above, unless he intended to hold that staurolite, cyanite, and andalusite were characteristic of Montalban schists; neither does it seem to us that any other construction is possible. It is to be further noticed that, in his reply to Professor Dana above quoted, Dr. Hunt emphatically denied the correctness of Professor Dana's statement, that he (Hunt) made in his Address the "White Mountains (Montalban) a newer series than the Green Mountain rocks" (Huronian). It does not appear to have occurred to Professor Dana that this denial was not made in good faith by Dr. Hunt, since he (Dana) replied as follows: —

"Mr. Hunt denies that he makes, in his Address, 'the crystalline schists of the White Mountains a newer series than the Green Mountain rocks' — I had read on pages 29 and 33 of the Address approving announcements that Macfarlane had made the crystalline rocks of the Green Mountains *Huronian;* and then, on page 34 of the Address, the statement that the White Mountain series is largely developed in Newfoundland, and that this fact had led him

(Mr. Hunt) to propose for it [the year before] the name of the *Terranovan* System. At this point in the Address there is a reference to this Journal of the preceding year, Vol. L, p. 87, 1870; and consequently by referring back to this article by Mr. Hunt, I found this Terranovan defined, Mr. Hunt saying that, according to Mr. Murray, the series comprises 'several thousand feet of strata, including soft bluish gray mica slates and micaceous limestones belonging to the *Potsdam* group, besides a great mass of whitish granitoid mica slates whose relation to the Potsdam is still uncertain.' As the Huronian is older than the Potsdam, and this equivalency of the Terranovan is not corrected in the Address, I thought I had reason for supposing that Mr. Hunt made the White Mountain series the newer. I acknowledge I prefer the view he now presents, since the less definite the statement the better as long as we have no sufficient facts for a conclusion." (Am. Jour. Sci., 1872, (3) IV., p. 105.)

Our extracts taken from Dr. Hunt's Address * show, however, that he did make the White Mountain series younger than the Green Mountain series, and that Professor Dana was correct. Furthermore, it will be shown that Dr. Hunt had advocated this view some time previous to his delivery of the Address; and that later he claimed to have advocated this order of age at the time of the Address and previously. The reader's attention is also called to the fact that in Dr. Hunt's Chemical and Geological Essays (p. 326) the sentence, "A careful perusal of my address will show that I nowhere assert that the rocks of the third series (Montalban), on my line of section, are younger than the second series" (Huronian), is expunged, although the paper purports to be a reprint of his reply to Professor Dana.

It is possible that the reader will find the reason for this expurgation in what follows. On May 1, 1871, some three and a half months before the Address was given, Dr. Hunt said: —

"In a communication to the *Boston Natural History Society* on the 19th of October last, and subsequently in the *American Journal of Science* for February and March, 1871 (pages 84 and 182), I have expressed the opinion that the porphyries . . . . are stratified rocks, belonging . . . . to the Huronian system, or Green Mountain system. . . . . I have in that same journal for July, 1870, pointed out the fact that the Eozoön of Hastings county, Ontario, occurs in a series of crystalline schists which I consider newer than the Huronian, and the equivalent of the White Mountain gneisses and mica schists." (Bull. Essex Institute, 1871, III., pp. 53, 54.)

Dr. Hunt's remarks, published in the Proceedings of the Boston Society of Natural History to which he above refers, are as follows: —

"I regard these two types of rocks (quartzo-feldspathic rocks and dioritic

* See *ante*, p. 447.

and chloritic rocks) as forming parts of one ancient crystalline series, which is largely developed in the vicinity of Boston, and may be traced at intervals from Newport to the Bay of Fundy, and beyond. To this same series I refer the great range of gneissic and dioritic rocks with serpentines, chloritic, talcose and epidotic schists which stretches through western New England." (*l. c.*, October 19, 1870, XIV., p. 46.)

The references to the American Journal are to a paper stated to have been read before the American Association, August 20, 1870, a year before the Presidential Address, and which was published in the Canadian Naturalist some eight months before that address was delivered.

He says, in the first reference to the rocks above referred to in the Proceedings of the Boston Society : —

"They apparently belong . . . . to the great Huronian series." (Am. Jour. Sci., February, 1871, (3) I., p. 84.)

The second reference reads as follows : —

"The rocks of this White Mountain series are, in the present state of our knowledge, supposed to be newer than the Huronian system . . . ., to which, with Macfarlane and Credner, I refer the crystalline schists with associated serpentines and diorites of the Green Mountains." (Am. Jour. Sci., 1871 (3) I., p. 182 ; Chemical Essays, p. 194 ; Canadian Naturalist, 1870, (2) V., p. 396.)

In Dr. Hunt's Azoic Rocks (pp. 222–224) is given part of a letter to Major T. B. Brooks, under date of February 22, 1871, nearly five months before the Indianapolis address. Since this letter is given in full in the Geology of Wisconsin, Vol. III., 1879, pp. 657–660, we prefer to take our extracts from that : —

"You remark about the *mica-schists* as being supposed by me wanting in the Huronian of Canada, and you send me Nos. 1215, 1154, 1152, 1153. Now I have for some time past recognized a *mica-schist series* which I supposed to overlie the Huronian, in fact the *White Mountain series*, provisionally named by me Terranovan [and since called Montalban]. See Am. Jour., July, 1870. I was therefore delighted to find in the specimens named well-characterized White Mountain mica-schists, holding garnets and well defined crystals of Staurolite [1153] ; while the peculiarly knotted mica schist is not less characteristic. These rocks are abundantly spread to the north of Lake Superior, as last year's collection show me ; but although I have not there been able to fix their relation to the Huronian diorites, talcose schists, iron ores, etc., I conclude, from the facts seen near Portland in Maine, and those described by Rogers in Penn., they are overlying rocks, and in some cases at least unconformably so. You say that 'they are the youngest rocks in the region

belonging to the Huronian.' I suspect that they belong to the same series. I distinguish three crystalline gneissic series : I. Laurentian (not to speak for the present of the Labrador), II. Huronian, III. Terranovan [Montalban] ; these being respectively in the United States, the rocks of the Adirondacks, the Green Mountains and the White Mountains. I hope you will be able to decide whether there is any want of conformity between II and III in your region. I should mention that in Hastings Co., Ontario, the three series all are represented, and that there is apparently a stratigraphical break between each. . . . . As regards series II, which was in 1862 declared by Macfarlane to be the same with the Green Mt. group, I have for some time been of that opinion, and have briefly expressed it in a paper on the rocks of E. Mass., read last October to the Bost. Nat. Hist. Soc. (not yet published), which compares the dioritic, chloritic and hornblendic rocks of the two series. Their copper, nickel and iron ores are characters in common. My opportunities for studying the Huronian had been very imperfect, as Mr. Murray's collections were so, and were made many years ago, and since remain, with few exceptions, packed away. It was not, therefore, till I saw the Huronian rocks displayed along the coast of New Brunswick, that I realized how much they were like the Green Mt. rocks, all of the types of which may be found on the Bay of Fundy from Eastport to the head of the bay. . . . . I have thus, I think, touched on the principal points of interest in your collection, of which the two great facts are the close resemblance, and I believe the identity, of the great *iron-bearing dioritic-talcose series*, with Green Mt. series II, and the equally close resemblance of the rocks, 1215, 1151 to 1154, with the White Mt. series III, which I conceive to belong to a higher horizon (see on this a note to my paper on granitic rocks, 2d part, Am. Jour. Sci. for March)."

While in the above letter it is written : "You say 'that they are the youngest rocks in the region belonging to the Huronian.' I suspect that they belong to the same series," — in the "Azoic Rocks," it reads : "You say that they are *the youngest rocks in the region belonging to the Huronian*. I suspect that they belong to *a younger* series." (*l. c.*, p. 223.)

Another letter by Dr. Hunt of the date of May 20, 1878 (Geology of Wisconsin, III., 1879, p. 660), contains the following : —

"The announcements made in my letter to you identifying the formations XIX and XX (the micaceous schists, with hornblendic and staurolitic schists and the white feldspathic gneisses) with the Montalban, which I at that time (1871) ventured to declare to belong to a newer and distinct series from the Huronian, were, as you know, an anticipation of some years of the published conclusions of yours that they are the *youngest Huronian rocks*, a strong confirmation of the great value of the distinctions, which in my letter to you of February 22, 1871, were presented *for the first time*. All my subsequent work in Pennsylvania (Proc. Amer. Assoc. 1876) and in North Carolina, as well as

Fontane's work in Virginia, have confirmed this. I count this a great point gained in American stratigraphy — the recognition of the *newer gneissic series* above the Huronian, to which I have given the name of *Montalban*. (The *Terranovan* suggested in 1870, was made up of *Montalban* and Taconian, as I have since shown.)"

Later, in the Azoic Rocks (pp. 224, 225), Dr. Hunt, in referring to the first letter given above, says : —

"The above conclusions as to this overlying gneiss and mica-schist series, was soon after made known by the writer, in his address in August, 1871, where it was said that the schists both of the Green Mountain and the White Mountain series ' are represented in Michigan, as appears by the recent collections of Major Brooks. . . . . He informs me that these latter schists are the highest of the crystalline strata in the northern peninsula. . . . . It was these schists, and the granitoid gneisses, from the Marquette region, which the writer [Dr. Hunt] so long ago as 1871, referred to the White Mountain or Montalban series, then, as now, placed by him above the Huronian — a testimony to the value of lithological characters in geology."

We thus see that Dr. Hunt had for over eighteen months advocated the view which he so emphatically denied having held ; and furthermore, that after the delivery of his Presidential Address he claimed to have held it at that time. Also, we have shown that he distinctly stated the same view in that Address. But it is unnecessary for us to comment on the methods of Dr. Hunt as revealed in the preceding extracts ; they speak loudly for themselves.

Professor Dana, in reference to Dr. Hunt's views regarding the age of rocks carrying crystals of staurolite, cyanite, or andalusite, remarked as follows : —

"Now the fact is that those same Taconic rocks, unquestionably of the Taconic system according to Emmons himself, and, therefore, Hunt attesting, of Lower Silurian age, contain in some places staurolite crystals." (Am. Jour. Sci., 1872, (3) IV., pp. 104, 105.)

Also, in the same paper, Professor Dana thus replied to Dr. Hunt's remark, that Emmons expressly excluded from the Taconic system all crystalline rocks : —

"This exclusion is an easy feat for a speculator with pen in hand, like many closet feats ; but it is more than herculean in actual fact, since the very Taconic mountains themselves, that is, the very rocks called Taconic by Emmons, are partly gneiss, gneissoid mica schist, and chloritic talcoid schist, as well as talcoid schist ; and these rocks are so involved together that speculation will never bring them into that kind of order which Mr. Hunt's notions require." (*l. c.*, p. 104.)

In a criticism on the Chemical and Geological Essays of Dr. Hunt, Professor Dana further states (Am. Jour. Sci., 1875, (3) IX., pp. 102, 103): —

"The reader of the volume will observe that in the Third Chapter the White Mountain series and Green Mountain series of rocks are made (as had been done by other geologists) Lower Silurian, and Upper Silurian and Devonian, in age, while in the Thirteenth Chapter (as also mentioned in the preface to Chapter III) both are pronounced pre-Silurian. In this, the older view, as I believe I have proved, is the one sustained by the facts. The new view is wholly speculative, being based on no careful stratigraphical study of the regions, but mainly upon the assumption that certain kinds of crystalline rocks are a test of geological age the world over. Since the first announcement of this doctrine by Mr. Hunt, I have spent many months in the study of the Green Mountain rocks and those of some other parts of New England, in order to ascertain whether there is any virtue in the criterion; and I have found none. Mr. Hunt makes staurolite evidence of pre-Silurian age; while, as I have shown, its crystals occur in crystalline rocks of New England that are not older than Upper Silurian. Such erroneous conclusions make it apparent that in reading the work the judgment should be held in reserve until the other side is heard. There is also another more serious reason for this reserve. For the volume contains a series of misrepresentations of the views of others wholly unnecessary to the presentation of the author's opinions, and difficult to find excuse for."

Professor Dana, in 1873, after discussing the observations of himself and others, remarks: —

"From the facts which have been presented it follows that all old-looking Green Mountain gneisses are not præ-silurian, and, further, that the presence of staurolite is no evidence of a præ-silurian age. . . . . It is not easy to avoid the conclusion that *the Taconic slates are Hudson river slates.* . . . . The Trenton limestone and Hudson River or Cincinnati groups, which properly constitute one series in American Geological History, are then *the true Taconic system.*" (Proc. Am. Assoc. Adv. Sci., 1873, XXII., B., pp. 25–29; American Naturalist, 1873, VII., pp. 658–660).

Professor Dana, in giving an account of an examination of the Helderberg rocks in the valley of the Connecticut (Am. Jour. Sci., 1873, (3) VI., p. 348), concludes that staurolite and andalusite occur in metamorphic rocks of any age, remarking that

"this Helderberg series in Central New England comprises a large part of the common kinds of metamorphic rocks, gneiss of several varieties, undistinguishable lithologically from the oldest; hornblende rock and schist; syenite gneiss; coarse mica schist and mica slate; staurolitic slate.

"A large part of the rocks that have been distinguished as of the 'Mont-

alban' or 'White Mountain series' in New Hampshire, and regarded of pre-Silurian age, are here included, and are hence nothing but altered Helderberg sediments. It is hence far from true that 'the crystalline rocks of the Green Mountain and White Mountain series' and 'the whole of our crystalline schists of Eastern North America are not only pre-Silurian, but pre-Cambrian in age.'"

In the same article (p. 341) Professor Dana further remarks: —

"Lithological evidence of a geological age among metamorphic rocks *of distant regions* is in general worse than worthless. It is easy to use, and presses itself on the mind most insinuatingly when a conclusion is eagerly wanted. . . . . I have further found that the Earth did not finish up its metamorphic work in pre-Silurian time, or even by the epoch closing the Primordial, as it did not its mountain-making."

For the field evidence upon which Professor Dana founded his conclusions, the reader is referred to the original article.

In the Report of Progress of the Canada Geological Survey, for the year 1873–74, Mr. Selwyn remarks that considerable doubt and uncertainty have been thrown upon the labors of Sir William Logan by articles from the pen of Dr. Hunt. These articles appear to the present head of the Canada Survey to indicate that the earlier views of Dr. Hunt in regard to the true stratigraphical positions of the rocks in Eastern Canada had undergone an almost entire revolution. This change of opinion is said by Mr. Selwyn to have been based, so far as he could understand it, on lithological comparisons exclusively, and he thus expresses his views in regard to that kind of evidence: —

"Whether the relative ages of great masses of crumpled and metamorphic strata can be thus determined apart from, or in the absence of palæontological and stratigraphical evidence, is a question which, as a stratigraphist of thirty years' experience, I should decidedly answer in the negative. The degree and character of the metamorphism and mineralization which a group of strata exhibit, cannot be relied on as certainly indicative of geological antiquity, and, as tending to strengthen this opinion, the recent researches of Mr. Richardson in British Columbia have shown that epidotic, chloritic and serpentinous rocks, with crystalline limestones and magnetites, are as characteristic of upper palæozoic, and perhaps also of even later formations when they have been subjected to an equal amount of plication and folding, as they are of the oldest palæozoic and protozoic strata, such as those of Eastern Canada and the New England States."

In 1875 Prof. J. P. Lesley stated that in Pennsylvania the Huronian or Green Mountain series was seen to overlie the White Mountain series; while he unqualifiedly placed both series in Vermont and New Hampshire below the Potsdam. (Second Geological Survey of Pennsylvania, D., pp. 65, 66.)

Professor Dana, in a review of Professor Lesley's remarks, says (Am. Jour. Sci., 1876, (3) XI., pp. 63, 64) : —

"Mr. Lesley goes outside of his field in his closing remarks, and states — what is sustained as yet by no adequate stratigraphical evidence — that the 'Green Mountain system of Vermont' and the 'White Mountain system of New Hampshire,' are, like 'the Laurentian Mountains of Canada,' older than the Potsdam; and that the Green Mountain system, one of these 'three great mountain systems of the north,' is Huronian. The observations by Mr. Prime in Pennsylvania, above mentioned, and the parallel facts in the Green Mountain system to which he draws attention, all point as regards the Green Mountains in the opposite direction. The writer has studied stratigraphically the Green Mountain region from Connecticut to Vermont, and has found that the hydro-mica and chloritic hydro-mica slates associated with the limonite beds of Berkshire are of the same formation with the hydro-mica, chloritic, and micaceous slates of Graylock and the Taconic range; and with the hydro-mica slates of the ridge lying northeast of Rutland in Vermont, and of others west and north of Rutland; and with the staurolitic schists of the limonite region of Salisbury, Connecticut. Since the limestones associated with the slates of West Rutland abound in distinct Lower Silurian fossils, referred to the Chazy by Billings, part of the Green Mountain slates and schists are unquestionably Lower Silurian. What is the age of the rest is not yet positively known."

In 1878 Professor Dana remarks : —

"Professor Lesley stated in his letter * that the opinions which he had derived, from the observations of others, more than thirty years since with regard to New England geology, he now (since the discovery of fossils in limestones among the metamorphic rocks of Vermont, of Bernardston and Littleton in the Connecticut Valley, and of Eastern Pennsylvania) regards as greatly strengthened in probability — namely : That Paleozoic rocks make up the Green Mountains, and also the White Mountains, and that the latter include beds of Devonian age." (Am. Jour. Sci., 1878, (3) XV., p. 261.)

This then is a virtual retraction by Professor Lesley of his statement in 1875 (given before), that the Green and White Mountains were pre-Potsdam in age.

Professor Dana made the following statement as the result of an extended series of observations † by himself and Rev. Augustus

* A letter to Professor Dana, giving an account of the discovery by Mr. Prime of Lower Silurian fossils associated with mica slates in Eastern Pennsylvania.

† For Professor Dana's various papers on this subject, see Am. Jour. Sci., 1872, (3) III., pp. 179–186, 250–256 ; IV., pp. 133, 362–370, 450–453 ; V., pp. 47–53, 84–91 ; VI., pp. 257–279 ; 1877, XIII., pp. 332–347, 405–419 ; XIV., pp. 36–48, 132–140, 202–207, 257–264 ; 1879, XVII., pp. 375–388 ; XVIII., 61–64 ; 1880, XIX., pp. 191–200. See also Dwight, Am. Jour. Sci., XVII., pp. 389–392 ; 1880, XIX., pp. 50–54.

Wing (Am. Jour. Sci., 1877, (3) XIV., pp. 202, 203; 1879, XVII., p. 387): —

"From the facts brought forward it is manifest that the limestone schists and quartzyte, making up the limestone series of Vermont and Berkshire, are *continuous* formations, and that they are *conformable* throughout. . . . . The limestone series is *made up wholly of Lower Silurian formations;* that is, of formations not older than the primordial or Cambrian, nor newer than the Cincinnati or Hudson River group. . . . . The Taconic mountains of western Berkshire are a direct continuation of the 'great central slate-belt' of Vermont. The two make one range and one rock-formation, and consist of the same kinds of rocks similarly upturned. . . . . In Vermont the Taconic slates (those of the central slate-belt) *overlie* the adjoining limestone in one or more synclinals, as plainly shown in Mount Dorset, Danby Mountain, Equinox Mountain, Spruce Peak in Arlington, and Mount Anthony in Bennington; and in Berkshire they have the same position, as observed in Greylock and Mount Washington. Hence in both States the *Taconic slates overlie, or are younger than, the adjoining limestone.* . . . . The Taconic schists are, according to the evidence, of the age of the Hudson River group."

The limestones and micaceous quartzites of Berkshire County, Mass., and elsewhere in New England, were stated by Dr. Hunt, in 1875, to belong to the White Mountain or Montalban series. (Proc. Bost. Soc. Nat. Hist., 1875, XVII., p. 509.)

In 1878 Dr. Hunt remarked (Preface, Chemical Essays, 2d ed., pp. xix.–xxii.) that the result of his study of the Taconic rocks had led him

"to conclude that what has been said of them in Essay XIII. Part 1, and in Essay XV. Part 3, is only true of that portion which Emmons at first included in the upper part of his Taconic system under the general name of the Taconic slates, but in 1855 separated from the underlying portions, and described as the Upper Taconic series. This is no other than the Quebec group of Logan, which is the northward prolongation of the Taconic slates from eastern New York. . . . . The strata of this region, and of its extension north and south, including the western border of the whole Atlantic belt, from the gulf of St. Lawrence to Alabama, have, as is well known, a general high dip to the eastward, attended with many dislocations, folds, and inversions; as a result of which the newer sediments appear to pass beneath the older ones, and even beneath the still more ancient crystalline rocks of the belt, giving rise to some of the most perplexing problems in American geology. The fauna of the Upper Taconic rocks, including the forms found at Troy, New York, at Georgia, Vermont, and at Phillipsburg, Point Levis, and Bic, in the province of Quebec, presents, as far as known, nothing lower than the Menevian horizon, and belongs to the Lower and Middle Cambrian of Sedgwick. . . . . The lower Taconic series of Emmons, embracing in ascend-

ing order (1) granular quartz rock, (2) the Stockbridge limestone with its interstratified and overlying micaceous schists, and (3) argillites, including roofing slates, constitutes a distinct geological horizon of rocks essentially crystalline, having an aggregate thickness of about five thousand feet. These are found resting alike on Laurentian, Huronian, and Montalban strata, and are overlaid, probably unconformably, by the Cambrian (Upper Taconic). . . . . They are apparently identical with the great limestone series which, in Hastings county, Ontario, underlies unconformably the Trenton group of limestones, and near St. John, New Brunswick, is beneath the Menevian slates."

During the same year the Taconian series was said by Dr. Hunt to include the statuary marbles of North America, and to be overlain "by the Upper Taconic, which is identical with the Quebec Group of Logan." (Nature, 1878, XVIII., p. 444; Geol. Mag., 1878, (2) V., p. 471.)

In 1879, Dr. Hunt gives us to understand that in 1863, when he referred the Green Mountain rocks to the Quebec Group, in the "Geology of Canada," he then regarded them as Huronian, but that "*official reasons then, and for some years after, prevented the writer from expressing any dissent from the views of the director of the geological survey of Canada.*" (Proc. Am. Assoc. Adv. Sci., 1879, XXVIII., p. 285; Am. Jour. Sci., 1880, (3) XIX., p. 273.)

It would seem from the remarks we have quoted from his papers* that the "official reasons" not only prevented his dissenting from Sir William Logan's views, but also caused him to affirm their correctness in the strongest possible manner. And in connection with this statement of Dr. Hunt's, it will be well to refer to one which follows, made by him in 1871: —

"My opportunities for studying the Huronian had been very imperfect. . . . . It was not, therefore, till I saw the Huronian rocks displayed along the coast of New Brunswick (1869–70), that I realized how much they were like the Green Mt. rocks." (Geol. of Wisc., 1880, III., p. 658.)

How again does Dr. Hunt's statement made in 1879 agree with that of 1875, in which reference is made to a paper read in 1863 advocating the palæozoic age of the rocks of the Green and White Mountains? The statement made in 1875 reads as follows: —

"My own extended studies of these rocks in the Green Mountains, in New Brunswick, and on Lakes Superior and Huron, have *since* convinced me that this view is correct, and that the Green Mountain series is represented in the crystalline strata around the great lakes just mentioned; and, moreover, that

* See *ante*, pp. 441–445.

both this series and the crystalline rocks of the fourth or White Mountain series existed in their present crystalline form before the deposition of the eldest Cambrian sediments."* (Chem. and Geol. Essays, p. 18.)

The following statement, made by Dr. Hunt in 1873, contains his own acknowledgment that he maintained, until 1870, views he would now have us understand he had not believed in since 1863.

"The question of the structure and origin of the Appalachians has been complicated by the assumption that the crystalline strata which constitute their higher portions are altered sediments of paleozoic age, rather than parts of an ancient continent of eozoic rocks which formed the eastern border of the paleozoic sea, corresponding to the Rocky Mountains on the west. The former view has been very generally held by American geologists, and was maintained by the present writer until 1870, when he endeavored to show that the crystalline rocks of New England and their lithological representatives both to the southwest and the northwest are of pre-paleozoic age and in part Laurentian. [This Journal, II. L, 83 . . . .]." (Am. Jour. Sci., 1873, (3) V., pp. 267, 268.)

The question arises, whether the geologist, who is desirous of finding out what Dr. Hunt's real views on any subject may be at the present time, or may have been at any time in the past, can feel any confidence that he is likely to arrive at a satisfactory result. At all events, it has been shown above that official or other conditions may be to Dr. Hunt a sufficient reason, not only for withholding his own views, but for strongly advocating that in which he himself has no belief.

In 1880 Professor Dana held that the Green Mountains were formed at the close of the Lower Silurian, and sums up the evidence on this point as follows (Am. Jour. Sci., 1880, (3) XIX., p. 200) :—

"1. The *western* half of the region between the Connecticut River valley and the Hudson River, that is, the western half of the Green Mountain area, is proved to consist of rocks that are (1) of Lower Silurian age and (2) of one orological system.

"2. The schistose rocks of the eastern half in Vermont are to a large extent similar to those of the western.

"3. The rocks of the central mountain section in Vermont are, in its northern part, identical schists (hydromica, etc.), with those on the east and west sides of it.

"4. The western border of the region in the Hudson River valley has its folded or upturned Hudson River (Lower Silurian) slates, overlaid unconformably by Niagara and Lower Helderberg (Upper Silurian) beds.

"The eastern border of the region in the Connecticut valley at Bernardston, in Massachusetts, Vernon in Vermont, and the adjoining part of New Hamp-

* The italics are ours.

shire, has lower Helderberg beds overlying, unconformably, folded or upturned roofing slates (similar to those on the western side), the Lower Silurian age of which is not improbable ; and at Littleton in New Hampshire, and on Lake Memphremagog, in northern Vermont, occur unconformable Upper Helderberg (Lower Devonian) beds with fossils. . . . . In view of these various considerations, the evidence, although not yet beyond question, is manifestly strong for embracing the whole region between the Connecticut and the Hudson (and to an unascertained distance beyond) within the limits of the Green Mountain synclinorium."

Professor Dana makes this statement in reference to a letter sent him by Prof. C. H. Hitchcock (Am. Jour. Sci., 1880, (3) XIX., p. 237) : —

"Prof. Hitchcock also says, in the recent letter to me, after remarking on his disbelief in 'Taconism' : 'Within the past two years I have gone over most of the Vermont sections, and have felt that they demonstrated the essential equivalence of the Taconic system with the Potsdam and the overlying limestones and slates [of the Lower Silurian]. I have been throughout in essential accord with you and Mr. Wing.' He adds that Mr. Wing's views had been his for years."

Professor Hitchcock is further quoted as saying regarding the Report on the Geology of Vermont (1861), "There is nothing in the Report anywhere favorable to 'Taconism.'"

In 1877 Professor Hitchcock gave his ideas of the Green Mountain or Quebec rocks as follows : —

"Sir W. E. Logan has described them under the general name of Quebec group. . . . . He has grouped together a large series of fossiliferous Cambrian and metamorphic rocks, assuming that the one was the equivalent of the other. I have endeavored to separate the fossiliferous from the metamorphic portions, with the assistance of Dr. T. Sterry Hunt. . . . . From this series, as proposed by Logan, we must eliminate all the fossiliferous portions and invert the order. . . . . This is in agreement with the recently quoted view of Mr. Macfarlane, and has been also insisted upon by Dr. Hunt. Separating the eastern part of the area called Quebec group by Logan, we may clearly understand it to be older than the fossiliferous Cambrian of any part of the world, and therefore to be named Huronian. . . . . The Vermont Huronian, save that along Connecticut river, is the southward continuation of the Quebec group of Canada. It is divided into two parts by the central ridge of the Green Mountains, which continues a few miles into Canada. Macfarlane follows the report on the geology of Vermont in regarding the Green Mountain ranges as older than the adjacent Upper Huronian. We have in that early publication (1861) insisted that these Green Mountain rocks underlaid the green schists upon both sides, ... and they are consequently older. The name Green Mountain gneiss, as applicable to this formation, was in use in

1846; and therefore the use of the same geographical designation by Dr. Hunt, in 1871, for the Huronian, is both inappropriate and improper, on account of prior usage. The Green Mountains are not Huronian at all, though flanked by it upon both sides in the northern half of Vermont. They belong to the Montalban series. Adopting the principle of inversion, as applied to the members of the Quebec group, we find they overlie these Montalban gneisses in the proper order of succession. As Macfarlan says, those who once accepted the theory of the metamorphism of New England seem to retain erroneous notions of the age of the successive mountain ranges, calling the Green Mountains newer than the Adirondacks, and the White more recent than the Green. They are both nearer the Laurentian than the Huronian, in respect to age." (Geol. of N. H., 1877, II., pp. 463, 464; see also pp. 10, 11, 25–27, 31.)

In 1875 he said: —

"His observations led him to believe that Emmons understood the stratigraphical relations of these rocks (many of them called Taconic by him) better than most of his contemporaries." (See Proc. Bost. Soc. Nat. Hist., 1875, XVIII., pp. 191–193.)

Professor Dana in a series of papers bearing the title of "On the Geological Relations of the Limestone Belts of Westchester County, New York," (Am. Jour. Sci., 1880, (3) XX., pp. 21–32, 194–220, 359–375, 450–456; 1881, XXI., pp. 425–443; XXII., pp. 103–119,) has brought together the evidence bearing on the question of the geological age of the Green Mountain limestones and associated rocks. He remarks as follows: —

"As the fossils of the limestone had been discovered only in Vermont, it was required, in order to extend the conclusions to the rest of the Green Mountain region, that the Vermont limestone should be proved to be the same stratigraphically with that of the region to the south, and this was done by ascertaining (1) the essential continuity of the limestone from the north to the south and south-southwest; and (2) its association with similar rocks from north to south, under similar stratigraphical relations; and finally (3), by the discovery of Lower Silurian fossils in the part of these belts of limestone that reach into and beyond Dutchess County, and also in the associated Taconic schists of that County. By these means, it has been shown that the schists of the Taconic range, the limestone belts on either side, and various conformable schistose rocks and limestone belts farther east and west, are comprised within the Lower Silurian formation, and that the whole series was displaced together in the upturning and metamorphism by which the Green Mountains were made." (Am. Jour. Sci., 1880, (3) XX., p. 22.)

Professor Dana comes to the conclusion, that the limestone of Westchester County and New York Island, and the conformably associated

metamorphic rocks, are of Lower Silurian age; also, that the limestone and the conformably associated rocks of the Green Mountain region, from Vermont to New York Island, are of the same age. He remarks furthermore: —

"These Westchester County rocks have been pronounced *Montalban*. I know of no facts sustaining such a conclusion. If true, it would follow, from the above, that the original Montalban rocks — those of the White Mountains — also are Lower Silurian." (Am. Jour. Sci., 1880, (3) XX., p. 455.)

Of the correctness of these statements in regard to the Lower Silurian age of the rocks in question, it seems to us that there can be no possible doubt.

NEW YORK.

The mass of the Adirondack Mountains is composed, in large part, of highly crystalline rocks, among which that called "hypersthene rock" by Professor Emmons is the most conspicuous and important, forming as it does the highest portion of the chain, and covering, according to the same authority, the whole of Essex County. Gneiss, granite, and syenite are also present over areas of some extent, while mica schist and talc schist are said to be entirely wanting. The extent and importance of the masses or beds of magnetic and specular oxides of iron are also well known. In Professor Emmons's classification of the Adirondack formation, gneiss and syenite are put down as being stratified, while the limestone is considered as being unquestionably of eruptive origin.

The Adirondack area is admitted by geologists — without exception, it is believed — to be Azoic, or Archæan. In view of what has been stated in the preceding pages with regard to the facility with which the Azoic rocks of other regions in this county have been assigned to be Laurentian, Huronian, or Montalban, or moved backwards and forwards between these three supposed systems to suit the fancy of the theorist, it seems rather remarkable that the rocks of Northern New York should have been so little meddled with in this way. Our knowledge of the geology of the Adirondack region is so exceedingly incomplete, that a fine field lies ready there for theoretical speculations of a kind similar to those which we have shown to have been so prevalent in regard to the rocks of New England. A brief statement will here be given of

what has been published bearing on the question of the division of the Adirondack rocks into two or more systems, first calling the reader's attention, however, to the fact that no one of the theoretical views advanced has been supported by sufficient evidence to make its adoption a necessity.

In 1864, Messrs. Hall and Logan announced, in a paper read before the Natural History Society of Montreal, (Canadian Naturalist, 1864. (2) I., pp. 368, 369; Am. Jour. Sci., 1865, (2) XXXIX., pp. 96, 97,) that the gneiss of the New York Highlands "presented all the aspects and characteristics of that of the Laurentian system, as seen in Northern New York and in Canada." Here it is assumed, as a matter of course, that the Adirondack region is Laurentian.

Nothing further appears to have been done until Mr. A. M. Edwards announced, in 1870, the discovery of *Eozoön Canadense* in serpentinous marble from Warren County, N. Y., this indicating, according to him, the Laurentian age of that rock. (Proc. Lyceum Nat. Hist. New York, 1870, pp. 96–98.)

Later, in 1876, Professor James Hall, in a paper entitled "Note upon the Geological Position of the Serpentine Limestone of Northern New York, and an Inquiry regarding the Relations of this Limestone to the Eozoon Limestones of Canada," (Am. Jour. Sci., 1876, (3) XII., pp. 298–300,) remarked of the Azoic area in question that the formations occupying that space, "originally called Primary, and afterwards Laurentian," were now known to "represent several geological periods." No proof of this is furnished; but it is further stated that there is a lower division of the Laurentian, "succeeded by massive beds of labradorite rock and other granite rocks." The lower division is said to consist of black hornblendic, gray garnetiferous, and coarse feldspathic and quartzose gneisses, with extensive beds of magnetic iron ore. The succession between this lower series and the upper one is said to be unconformable. In regard to this unconformability it is further stated that "the interval between the two series of rocks is not determined, nor does it appear to be determinable from examinations thus far made within the State of New York."

Professor Hall makes a third unconformable series out of the limestone masses of that region, of which rock he says that it "unconformably overlies the upturned edges of the gneissic beds." He also further states that this limestone "does not conform to the upper or labradorite portion of the system." Hence, he considers that the limestone in question "does not belong to the Laurentian system, either lower or

upper." He concludes by suggesting the inquiry "whether the Eozoon limestones of Canada, which are associated with Laurentian rocks, and have been referred to that age, are really Laurentian."

Professor Hall's idea of making a separate geological formation or system out of the limestone masses of Northern New York, on account of their unconformable position, is hardly less remarkable than that of Professor Emmons, who considered that the peculiar occurrence of this rock in the region in question could not be accounted for except on the supposition that they were of eruptive origin. It seems to us, on the other hand, that these limestone occurrences are, very probably, similar in character to those of Eastern Massachusetts, which are not a part of the stratified formation, but rather of the nature of segregated masses, or chemical precipitates, as will be more fully set forth farther on in this paper.

Prof. A. R. Leeds, in a paper entitled "Notes upon the Lithology of the Adirondacks," concluded

"that the rocks of Essex County are part of the Norian System," and "that these norites are a stratified rock, but have undergone a metamorphosis so profound as to have caused them to be regarded by Prof. Emmons and earlier observers as unstratified. The dolerites which are found of the same constituent minerals, and are of the mean specific gravity of these norites, have probably been formed from a portion of these stratified deposits by deeply seated metamorphic action, and have further modified and greatly tilted the superposed rocks in the course of their extrusion." (American Chemist, 1877, VII., p. 339.)

That these rocks belong to the Norian system was determined by lithological evidence, which really means no more than this, that gabbros coming from different localities look somewhat alike. That the rocks are stratified is, according to him, shown by the existence of a more or less complete parallel arrangement of the constituent minerals. Professor Leeds is a chemist, and not a petrographer; and since his ideas are obviously simply a repetition of those of Dr. Hunt, his testimony neither adds to nor detracts from the importance of the theoretical views of the latter.

Mr. N. L. Britton, in 1881, in an article on the geology of Richmond County, N. Y., (Annals of the N. Y. Academy of Sciences, 1881, II., pp. 161–182,) advocates the view that the granite observed by him at Tompkinsville is an Archæan metamorphosed rock. This granite is said by him to be "very coarsely crystalline in structure," and no stratification is observable in it. No proof is furnished that it is of metamorphic origin.

The serpentine, which forms so conspicuous a feature in the geology of Staten Island, is thought by Mr. Britton to be a metamorphosed magnesian limestone. The sections drawn to illustrate the geology of the region show the serpentine always occurring as a sort of mantle enveloping the gneiss. These sections, which seem to be a pure fiction of the imagination so far as the relations of the serpentine and gneiss are concerned, do not agree with the geology as laid down on the accompanying map. Since, as is well known, a large part of the thoroughly-studied serpentines of the world have been proved to be the result of the metamorphism of eruptive masses, it seems more reasonable to ascribe such an origin to the rock in the region under consideration. At all events, the sections given do not favor the idea of such an origin of the serpentine as is advocated by Mr. Britton; nor is it by any means proven that the belt of metamorphic rocks which runs through Staten Island is, as he supposes, older than Lower Silurian.

NEW JERSEY.

In the Report of the earliest Geological Survey of New Jersey, by Prof. H. D. Rogers, the gneissic belt which traverses that State from northeast to southwest in its northern portion is called primitive, and the crystalline limestones which accompany it are supposed to be the result of an alteration of the Blue Limestone by the agency of dikes of granite. The beds or masses of iron and zinc ore, which characterize the gneissic belt, are said to be "unequivocally genuine lodes or veins." The later Survey, first under the direction of Dr. Kitchell, and later under that of Professor Cook, agree in making the crystalline limestones a portion of the gneissic formation. In regard to the iron ores, Professor Cook states (Geology of New Jersey, 1868, p. 44) that the majority of geologists now think them to be true beds, "which were deposited as sediments, in the same way as the material for the gneiss rock."

By Professor Cook the whole system of rocks, including the gneiss and crystalline limestones, together with the associated iron and zinc deposits, are considered as belonging to the "Azoic formation." These rocks are overlain, as represented in the published sections, by the

Potsdam sandstone in unconformable sequence. It was found by Professor Cook that it was not practicable to divide the Azoic of New Jersey, or to make of it "any other systematic classification than a geographical one." It will therefore not be necessary for us, in this connection, to dwell upon the geology of the lower rocks in this State. Since, however, this admirably conducted Survey is still in progress, and it will yet be possible to obtain from it valuable additions to our present stock of knowledge of that region, it will be well to call attention to certain points in regard to which evidence is still lacking to prove the correctness of the common belief about them.

The relations of the different Azoic rocks to one another should be most carefully studied, in order to find out whether the supposed gneiss is, as a whole or in part, sedimentary or eruptive, the laminated character not being sufficient to prove its origin, lamination being a very common character in eruptive rocks. The contacts of the rocks require very careful examination, as it is only in this way that it will be possible to make out the relative age, and in most cases the origin, of the rocks in question. Of the rocks, the first one in order of time should have its origin determined by study of its intimate structure, and by comparison of it with similar rocks of known formation. It would be necessary to remember that unconformability between the lamination or foliation of an eruptive rock, and the stratification planes of a sedimentary one, means something very different from the unconformability of two stratified deposits. Attention should be specially paid to the kind of contact made by the supposed Azoic with the Palæozoic, and examination should be made to see whether the latter at its base is composed of *débris* derived from the supposed Azoic. The one case in which the material of a conglomerate is referred to the gneissic rocks is a doubtful one, and, if correct, would only show that the gneiss is older than the Oneida conglomerate. (Geology of New Jersey, 1868, pp. 335, 336.)

In the case of the iron ores associated with the Azoic, the evidence given seems to be insufficient to prove the view either of their sedimentary origin or of their eruptive character. Statements in regard to the apparent conformable stratification and insensible passage of one rock into another have been often made, and are easy to make; but such statements require proof based on most careful observation, made by thoroughly skilled petrographers, before they can be accepted as conclusive evidence in regard to the question at issue.

PENNSYLVANIA.

The views of Prof. H. D. Rogers, former State Geologist of Pennsylvania, in regard to the lower formation in the region embraced within his Survey, have already been briefly mentioned.* Two years later than the date of the publication to which reference is there made — in 1858, namely — his Final Report appeared. In this Report, Professor Rogers adheres, essentially, to the ideas maintained by himself in the article in Johnson's Physical Atlas. In the introductory chapter to Part I. of the Final Report, under the heading of "Classification of the Metamorphic Strata of the Atlantic Slope of the Middle and Southern States," he discusses certain questions which pertain to the subject of this paper. He remarks, that, previous to the light thrown upon the older rock formations of the Atlantic Slope by the Geological Surveys of Pennsylvania and Virginia, these rocks were supposed to constitute but one group, and were included under the name of "Primary," and he then proceeds to make the following statement: —

"Early, however, in the course of those surveys, it came to light that by far the larger portion of the rocky masses of at least the middle and northwestern tracts, including much of the Blue Ridge and of the Green Mountains, were of a different type and age from the oldest metamorphic or true gneissic system. The evidence in support of this conclusion was, first, an obvious and very general difference in the composition of the two sets of strata; secondly, a marked difference in their conditions of metamorphism; and thirdly, and more especially, a striking contrast in the direction and manner of their uplift, the plications and undulations of the less metamorphic series dipping almost invariably southeastward, while the gneiss in many localities has no symmetrical foldings, but only a broad outcrop dipping to a different quarter." (*l. c.*, pp. 62, 63.)

From the above statement it would appear that there could have been no difficulty, in the course of the Survey, of drawing the line thus said to be perfectly well defined by "*an obvious and very general difference in the composition of the two sets of strata*," by "*marked differences in their condition of metamorphism*," and finally, by "*a striking contrast in the manner and direction of their uplift.*" One is surprised to find, however, that all the above-stated differences were not realities, but "inductions," and that it was not "*until a relatively late date in the prosecution of the Geological Survey of Pennsylvania, that the geologist of that State detected positive evidences of this physical break, and of a lapse of time be-*

* See *ante*, pp. 440, 441

tween the two groups of strata, and established, by ocular proof, the correctness of the previous induction."

In accordance with this latter statement, and not with the former, we do not find on the general geological map of the State accompanying the Final Report any indication of the two groups in question. All the crystalline rocks seem to be indicated by a single color, and included under the term "hypozoic."

Reading still farther in Professor Rogers's Report (*l. c.*, p. 63), we are even more surprised than before, when we learn that

"Assembling all the evidence which we now possess, we have in the Atlantic Slope, by actual demonstration, but one physical break or horizon of unconformity throughout the whole immense succession of altered crystalline sedimentary strata, and within this region but one Palæontological horizon, — that, namely, of the already discovered dawn of life among the American strata. This latter plane or limit, marking the transition from the non-fossiliferous or azoic deposits to those containing organic remains, lies within the middle of the primal series or group of the Pennsylvania survey, that is to say, in the primal white sandstone. . . . . The Primal slates beneath the sandstone, and in intimate alternation with it, possess not a vestige of organic life, nor has any such been yet discovered anywhere within the limits of the Atlantic Slope, or on the northern or western borders of the Great Appalachian Basin of North America."

Farther on in his Report, Professor Rogers remarks concerning his two systems of rocks, — the Hypozoic or Gneissic, and the Azoic, — that "the members of the two groups often simulate each other so closely, and *are indeed so identical in mineral aspect and structure, as to baffle all attempts at distinguishing them lithologically.*" Again, we are informed that these systems are nevertheless distinct from each other, and "susceptible of delineation on the geological map." But, it is immediately added, "the State geologist did not venture to define them on the map."

Before proceeding to notice the results attained by the Second Geological Survey of Pennsylvania, in connection with the investigation and classification of the crystalline rocks of that State, it will be well to refer to the views published by Dr. Hunt at various times between the completion of the First Survey and the beginning of the Second. This is the more desirable, because he was employed by the State Geologist (Professor Lesley) "*to collate all the known, supposed, and suspected facts of American Azoic Geology*" for publication by that Survey, apparently as a sort of manual or guide to the mysteries of that department of the science, for the use of future investigators. Professor Lesley considers

that "a debt of gratitude is due Dr. Hunt for his historical monograph," although admitting that "no final demonstration has been accomplished by the author [Dr. Hunt] of those problems of superposition, unconformability, and identification, at which so many geologists are still half despairingly at work." (Azoic Rocks, p. vii.) Perhaps this admitted want of success will not be so difficult to account for, when one takes into consideration some of the views published by Dr. Hunt previous to his engagement on the Pennsylvania Survey.

In 1861, Dr. Hunt remarked, regarding the Hypozoic or Gneissic series of Professor Rogers (Am. Jour. Sci., 1861, (2) XXXI., pp. 394, 395): —

"We have along the great Appalachian chain, from Georgia to the Gulf of St. Lawrence, a third series of crystalline strata, which form the gneissoid and mica slate series of most American geologists, the hypozoic group of Prof. Rogers, consisting of feldspathic gneiss, with quartzites, argillites, micaceous, epidotic, chloritic, talcose and specular schists, accompanied with steatite, diorites and chromiferous ophiolites. This group of strata has been recognized by Safford in Tennessee, by Rogers in Pennsylvania, and by most of the New England geologists as forming the base of Appalachian system, while Sir William Logan, Mr. Hall, and the present writer have for many years maintained that they are really altered palæozoic sediments, and superior to the lowest fossiliferous strata of the Silurian series. Sir William Logan has shown that the gneissoid ranges in Eastern Canada have the form of synclinals, and are underlaid by shales which exhibit fossils in their prolongation, while his sections leave no doubt that these ranges of gneiss, with micaceous, chloritic, talcose and specular schists, epidosites, quartzites, diorites and ophiolites, are really the altered sediments of the Quebec group, which is a lower member of the Silurian series, corresponding to the Calciferous and Chazy formations of New York, or to the Primal and Auroral series of Pennsylvania. Prof. Rogers indeed admits that these are in some parts of Pennsylvania metamorphosed into feldspathic, micaceous and talcose rocks, which it is extremely difficult to distinguish from the hypozoic gneiss, which latter, however, he conceives to present a want of conformity with the palæozoic strata. To this notion of the existence of two groups of crystalline rocks similar in lithological character but different in age, we have to object that the hypozoic gneiss is identical with the Green Mountain gneiss, not only in lithological character, but in the presence of certain rare metals, such as chrome, titanium, and nickel which characterize its magnesian rocks; all of these we have shown to be present in the unaltered sediments of the Quebec group, with which Sir William Logan has identified the gneiss formation in question. Besides which the lithological and chemical characters of the Appalachian gneiss are so totally distinct from the crystalline strata of the Laurentian system, with which Prof. Rogers would seem to identify them, that no one who has studied

the two can for a moment confound them. Prof. Rogers is therefore obliged to assume a new series of crystalline rocks, distinct from both the Laurentian and Huronian systems, but undistinguishable from the altered palæozoic series, or else to admit that the whole of his gneissic series in Pennsylvania is, like the corresponding rocks in Canada, of palæozoic age."

In the Presidential Address of Dr. Hunt before the American Association, 1871, it is stated that Prof. H. D. Rogers has distinguished three districts in Pennsylvania of various crystalline schists, which, in his Report on the geology of that State, he included under the name of Gneissic or Hypozoic rocks. The gneiss of the northern or South Mountain belt is said by Dr. Hunt to be "lithologically as well as geognostically identical with that of the Highlands, and belongs like it to the Adirondack or Laurentian system of crystalline rocks." The gneiss of the middle district seems to be regarded as Laurentian, while that of the third or southern district is referred to the White Mountain series, with the exception of the middle subdivision, which is said to present the aspect of the second or Green Mountain series.

Professor Rogers is stated to have placed above the hypozoic gneisses his azoic or semi-metamorphic series, which Dr. Hunt regards as belonging to the Green Mountain or Huronian series, in regard to which he remarks as follows : —

"The azoic or so-called metamorphic primal strata are said to have a very uniform, nearly vertical, dip, or with high angles to the southward, while the micaceous and gneissic strata of the northern subdivision of the southern district of so-called hypozoic rocks, limiting these last to the south, present either minute local contortions or wide gentle undulations, with comparatively moderate dips, for the most part to the northward. From this, I think we may infer that the nearly vertical strata must be, in truth, older underlying rocks, belonging, not to the palæozoic system, but to our second series of crystalline schists." (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 7–9.)

It seems, although we were, in 1861, emphatically informed that the "*lithological and chemical characters of the Appalachian gneiss are so totally distinct from the crystalline strata of the Laurentian system, ... that no one who has studied the two can for a moment confound them,*" that now we are as positively told that part of it is "*lithologically as well as geognostically identical with . . . .* [*the*] *Laurentian system of crystalline rocks.*"

In 1875 Prof. J. P. Lesley stated that the Huronian or Green Mountain series seems to overlie the White Mountain series in the vicinity of Philadelphia; also, that the conglomerate beds of the Primal series hold

pebbles of Huronian rocks. (Second Geological Survey of Pennsylvania, D, p. 66.)

In 1876, he says that the middle zone of gneiss of Rogers is "now known to be Laurentian." (*l. c.*, A, p. 136). It is well known that in general Dr. Hunt claims a reverse order, or that the Montalban overlies the Huronian.

In 1876 Dr. Hunt referred the ores, found along the borders of the Mesozoic red sandstone, and including the Cornwall mine, to the Lower Taconic (Taconian); but no evidence was given to show the justness of this conclusion. (Trans. Am. Inst. Min. Eng., 1876, IV., p. 320.)

During this year he also referred other rocks in Pennsylvania to the Laurentian, Huronian, and Montalban. This determination seems to have been based exclusively on lithological characters, no further evidence except difference in the strike of their supposed stratification planes being advanced. The Primal slates and sandstones of Rogers were regarded by Dr. Hunt as Lower Taconic (Taconian). (Proc. Am. Assoc. Adv. Sci., 1876, XXV., pp. 208–212.) He also makes the White Mountain (Montalban) series in the vicinity of Philadelphia to overlie the Huronian, although Professor Lesley states that the reverse appears to be the case.

In Professor Frederick Prime's Report (Second Geological Survey of Pennsylvania, DD, 1878) the gneissic rocks in Lehigh County are called Laurentian. In one locality he says that

"the junction of the Potsdam sandstone and Laurentian rocks can be well seen. The dips of the two rocks seem to be conformable, but this may be wrong, as the exposure is small and the gneiss apparently has a slight roll. The gneissic rock is here distinctly bedded."

It is probable that Professor Prime uses the term "distinctly bedded" for "distinctly foliated," terms which have not as yet been proved to be synonymous. He further says: —

"It is possible that these gneissic rocks which seem to lie conformably with the sandstone, and which are true gneisses, are in reality Lower Potsdam." (*l. c.*, pp. 9, 10.)

In 1877, Professor Prime advances some evidence to show that the Potsdam sandstone was deposited upon the gneiss and made out of its ruins; had he deemed this determination a matter of as much importance as it seems to us to be, he would doubtless have investigated the matter more closely. It is to be hoped that this may yet be done. He shows that the mica schists (hydro-mica slates) lie between the Potsdam

sandstone and Magnesian limestone, conformable with both, and that they therefore cannot belong to the "Taconian" of Hunt, as the latter had stated. Professor Prime also says: —

"It is well here to emphasize the fact that these brown hematite ores all belong to the Lower Silurian limestone formation, since, in 1875, Dr. Sterry Hunt, after a cursory examination of Ziegler's Mine in Berks County . . . . made the mistake in a paper on 'The Decay of Crystalline Rocks' before the National Academy of Science, of supposing that the hydromica slates belonged to the Huronian Period: — a mistake into which so eminent an observer as himself would never have fallen had he been better acquainted with the region." (Proc. Am. Phil. Soc., 1878, XVII., pp. 248–254; Am. Jour. Sci., 1878, (3) XV., pp. 261–269.)

Mr. Charles E. Hall thus indicates the formations of Eastern Pennsylvania, in their ascending order (Proc. Am. Phil. Soc., 1880, XVIII., pp. 435–443): —

First. A series of granitoid, syenitic, quartzose, and micaceous schistose rocks.

Second. A series of syenitic, hornblendic and quartzose rocks. He states, however, that "this series may be the upper members of the first."

Third. Potsdam sandstone, conglomerate, quartzite, and occasional schistose beds. "This, the Potsdam sandstone, rests unconformably upon the preceding two groups. The unconformity is seen at points east of Willow Grove, where the lower conglomerates contain fragments of the syenitic rocks."

Fourth. Dolomites, schistose or slaty micaceous beds, limestone, marble, hydromica schists, and bastard marble. "This group of limestones and schists rest on the above group, and are the equivalent of the Cambrian limestones of the Great Valley."

Fifth. Hydromica schists, quartzose schists, chloritic schists, and occasional beds of quartzites and sandy beds and serpentines.

Sixth. Micaceous, garnetiferous schists, limestone, mica schists and sandstones. "This group rests unconformably upon the western extension of the *second* group."

Seventh. "The mica schists of Philadelphia, mica schists, hornblendic, garnetiferous, talcose schists with soapstone and serpentine. . . . . They rest unconformably upon the first, second, third and fourth groups. . . . . There are besides these groups probably two serpentine horizons, which are undoubtedly unconformable deposits above the second group. I think the northern belt of serpentine may be considered as altered Hudson river rock; while the southern belts are doubtful."

The slates of Chester, York, and Lancaster Counties (including the Peach Bottom slates), as well as the serpentines of Radnor, Easttown, Willistown, and East and West Goshen, are stated to be undoubtedly

of Hudson River age. (See also Am. Jour. Sci., 1880, (3) XIX., pp. 413, 414.)

From the above it will be seen that Mr. Hall makes his first and second groups — which, however, he seems to think may perhaps belong together — to be older than the Potsdam Sandstone, which overlies them unconformably. None of the rest of his groups can, therefore, be of Azoic age. This is a result very different from that attained by Dr. Hunt and others, who have made most of this region pre-Silurian. But Mr. Hall's views seem to have a substantial basis of observation, while Dr. Hunt's cannot be regarded as anything more than theories based on lithological resemblances. How fanciful these are may be inferred from the contradictory statements of that author himself in regard to the rocks in question.*

By way of illustrating the difficulty of separating the lower formations from each other in the crystalline belt of Pennsylvania, it may be well to add one or two extracts from the latest publication of the present Survey of that State ; — "The Geology of Chester County, after the Surveys of Henry D. Rogers, Persifor Frazer, and Charles E. Hall. Edited by J. P. Lesley [State Geologist], C^4, 1883." In this publication two maps are given, one of which embodies the conclusions reached by Professor Rogers, the other those of Mr. C. E. Hall, the region embraced in these maps being essentially the same, and forming part of Delaware and Chester Counties. A comparison of these maps will show how utterly unlike they are ; but perhaps it will be better to quote Professor Lesley's own language on this point. He says (*l. c.*, p. viii.) : —

"It is impossible to imagine a greater contrast than between these two illustrations of opposite views. The great regularity of Mr. Rogers' belts, the utter irregularity of Mr. Hall's areas, strikingly exemplify the difference between the conclusion arrived at, in a difficult region like this, by the earlier geologist who made everything bend to his theory of parallel overturned anticlinals and synclinals, and the observations of the later geologist who is fettered by no such theory, but is perhaps quite as strongly influenced by a different sentiment, viz. : that the Azoic formations spread out over one another with moderate inclinations unconformably."

Furthermore, the following may be quoted from the same source, as illustrating the facts that even the later geologists — those, namely, who have worked longest and most perseveringly in this difficult field — have not been able to arrive at concordant results. Professor Lesley remarks (*l. c.*, p. 34) : —

* See *ante*, pp. 469, 470.

"Since 1858 the district in question has been closely and repeatedly investigated by Prof. Frazer and Mr. Hall, the one approaching it from the west, the other from the east. They differ radically in their views of the order and superposition of the formations, not only from Prof. Rogers, but from each other; so that this report will leave several points of geology in almost as great obscurity as ever."

Finally, the following may be commended to the consideration of the reader (*l. c.*, p. 53): —

"It will be seen from the summary of Prof. H. D. Rogers' observations in 1851, given above, that he was guided everywhere by a theory of parallel *anticlinal folds* in the great Azoic or Hypozoic strata; and of intermediate *synclinal troughs*, some of them wide and deep, others narrow and shallow, but all of them containing preserved remnants of more micaceous strata, of a later age, but probably older than the hydro-mica slates of the South Valley hill. In no respect however does he settle the great question of what the true relationship may be between the older and newer gneisses, — between the newer gneisses and the talc-mica-schists, — between the talc-mica-schists and the sandstone (quartzite) — between the quartzite and limestone — between the limestone and serpentine — in the southern townships of Chester county. After an apparently copious and precise array of facts the geology of the whole district remains as confused and obscure as ever. The section along the Schuylkill is the key to the lock; but the key will not turn in the lock; the door remains closed. . . . . We travel to and fro across the hills and find no clue to guide us out the labyrinth of infinitely various and yet strangely similar deposits, the strike of which is everywhere more or less doubtful to the eye and tempting to the imagination."

VIRGINIA.

Prof. W. M. Fontaine states that certain coarse syenites and granites in the vicinity of Balcony Falls and the Peaks of Otter, "from their stratigraphical relations and composition," are plainly of Laurentian age. These rocks appear to be regarded by him as being eruptive in many places. Since he assumes without any apparent evidence, except the "*look*" of the rocks, the passage of sedimentary rocks into remarkable metamorphic forms, and also that other rocks are eruptive from the same evidence (their "looks"), his statements relating to crystalline rocks need in most cases to be accepted with caution until the proof is presented. It is doubtful if the supposed primordial rocks are of that

age. Should they hereafter be shown to be Primordial, all that Professor Fontaine's evidence shows is an older series of rocks containing eruptive granites, syenites, etc. His writings are far from being clear, but we are unable to find any proof in them that the granite and syenite are of different geological age from their associated rocks. (Am. Jour. Sci., 1875, (3) IX., pp. 14–22, 93–101, 361–369, 416–428.)

It would appear that Prof. J. L. Campbell regards the Laurentian granites and syenites of Professor Fontaine as eruptive rocks, erupted since the deposition of the supposed Primordial strata, thus leaving only one formation *in situ* under the supposed Primordial. Professor Campbell holds, however, that the eruptive syenites and granites are metamorphosed, and displaced underlying formations. In another locality he seems to regard the syenite as a "syenitic gneiss (or stratified syenite), which might readily be taken for an igneous rock — so greatly has it been metamorphosed"; but he fails to give any evidence that it is not igneous, or any reasons why it should be regarded as a metamorphosed sedimentary rock. He also fails to show that the supposed Primordial is composed of the *débris* of his supposed Archæan. As has been before remarked in other similar cases, it is not here our intention to assume that the conditions are not as they are assumed to be; it is simply our wish to call the attention of the observers to the fact that their published observations fail to furnish the proof necessary to be presented before these ideas can be accepted as axioms. They are not of the nature of self-evident truths. (Am. Jour. Sci., 1879, (3) XVIII., pp. 16–29, 119–128, 435–445.)

The latest setting forth of Professor Fontaine's views on the subject here under discussion will be found in a letter from himself to Professor Lesley, dated January 20th, 1883. (Second Geological Survey of Pennsylvania, Report, C⁴, 1883, pp. xiii.–xvi.) In this letter he clearly assumes that the division of the Azoic rocks into Laurentian and Huronian is to be taken for granted as something so clearly established that it must stand, no matter how difficult it may be to reconcile the theory with the facts. The Huronian seems to be wanting; that is, he finds it very difficult to discover rocks having the proper lithological characters. Thus he says (*l. c.*, p. xiii.): —

"The Blue Ridge in the northern part of Virginia is, as I take it, much as it is in your South Mountains of York, &c. The Huronian strata hide very largely the Laurentian. On the Potomac the latter does not show at all. . . . . The Laurentian sinks and expands as we go south in Virginia, and often has over it a mere remnant of the Huronian. . . . . Still farther south-

ward, in the counties of Floyd and Carroll, I could find no typical Huronian, such as the chlorite rocks, the felsite, &c."

Throughout the whole of this communication it appears clearly that Professor Fontaine considers that the terms Huronian and Laurentian are simply names for certain lithologically peculiar rocks. Chlorite schists are called "typical Huronian," and gneisses "Laurentian"; but it is easy to see from his description that the two, with the other ordinarily associated rocks, occur together, sometimes one predominating and sometimes another, in a manner perfectly characteristic of the Azoic series as a whole, yet utterly in opposition to their existence as separate and distinct systems.

NORTH CAROLINA.

In the Report of Prof. W. C. Kerr on the Geology of North Carolina (1875), a large portion of the rocks of that State is assigned to the Laurentian and Huronian formations. Three distinct belts of Laurentian are recognized. The eastern one

"consists of light colored and grey gneisses, which occasionally pass into granite, but more frequently into felspathic, quartzose (and rarely hornblendic) schists. In some localities the mica is entirely wanting, and then the rock is either a dull-reddish, brownish, or whitish massive felspathic rock, trachyte, euryte, felspar porphyry, &c." (*l. c.*, p. 122.)

The Edgecombe granite, which Professor Kerr regards as a metamorphosed sedimentary rock (gneiss), "shows no gneissic or foliated structure, being undistinguishable from true granite."

In the second area (*l. c.*, pp. 123–128), —

"the characteristic and prevalent rocks are syenyte, doleryte, greenstone, amphibolyte, granite, porphyry, and trachyte . . . . The most common rock is of a hornblendic character; and traps, trachytes, granulytes and porphyries are confusedly and angularly wedged in among each other, with frequent veins of epidote crossing the felspathic species in every direction. . . . . The absence of anything like stratification or foliation is conspicuous throughout the region. . . . . If there be any significance in structure or in lithological characters, this singular body of rocks seems entitled to be placed at the very base of the Archæan age, certainly at the bottom of the Laurentian; and even below these, if there be any older rocks exposed anywhere, — the true Azoic or

Igneous. In the direction of this notion certainly point the absence of stratification, the non-occurrence of limestone, and the great predominance of syenytes (mostly hyposyenyte), and other iron-bearing and basic rocks. I have only placed them as the lower Laurentian, however, since there seems to be a general disinclination to suppose that the primal igneous core anywhere shows itself to human inspection. This belt may well be characterized as the geological axis of the State. The group of rocks just described is bounded on the northwest by a series of gneisses and feldspathic and occasionally hornblendic slates, which extend westward, with little interruption to the Blue Ridge, and, except a narrow zone of a few miles breadth along the course of that chain, includes the whole mountain region to the flanks of the Smoky Mountains, through the greater part of its length. These are considered to belong to the Laurentian proper. . . . . A few miles west of this is a narrow terrane of syenytes and other hornblendic rocks and granites. . . . . The predominance of hornblendic rocks, the absence of mica, and the general absence of stratification have seemed to justify the reference of this belt to the lower part of the series, along with the preceding central zone. . . . . Another considerable area of Laurentian rocks is found beyond the Blue Ridge, occupying most of the mountain plateau between that and the Smoky Mountains, and in places constituting the materials of these chains. As stated before, this area may very properly be considered as only a continuation of the preceding, from which it is divided by a very narrow and interrupted belt of Huronian slates. . . . . The rocks of both of these, like those of the preceding area, are foliated for the most part, and consist of indefinite alterations of the same kinds of metamorphic strata, — gneiss, hornblendic, feldspathic and micaceous schists, and occasionally chloritic and talcose slates."

In regard to the principal Huronian belt, Professor Kerr makes the following statement (*l. c.*, p. 133) : —

"The belt is bounded on both sides by the Laurentian, already described, on which it lies unconformably, and from which its materials were derived. The stratigraphy therefore indicates the horizon of these rocks to be the Huronian, and the lithology agrees well with that determination; and the reasonable course therefore seems to be, to place them as Huronian, until some evidence shall be found of an organic character, to lift them to a higher geological plane. The absence, or at least the non-discovery of fossils hitherto, in an extensive body of slates like those of the middle and west portions of this tract, so little altered and so well adapted to the preservation of even the most delicate organisms, and in a region so much studied, and on account of numerous mines, offering so good opportunities for the discovery of fossils if any existed, is certainly so far confirmatory of the sub-Silurian theory of these deposits. This is the principal area of Emmons' Taconic in this State."

Prof. F. H. Bradley, however, who had made a special study of the rocks of Eastern Tennessee, subsequently examined a considerable por-

tion of Western North Carolina, as well as the adjacent regions of Georgia and Alabama. In a series of papers entitled "On the Silurian Age of the Southern Appalachians," (Amer. Jour. Sci., 1875, (3) IX., pp. 279–288, 370–383,) this geologist reaches conclusions which he thus states: —

"The rocks of that portion of North Carolina south and west of the Little Tennessee, together with the metamorphic area of Georgia, north of a line parallel with and ten miles south of the Chattahoochee (and *probably* that south of this line), and the entire metamorphic area of Alabama, are *Silurian or newer*, with the possible exception of two or three small patches not over ten miles in diameter." (*l. c.*, p. 280.)

Professor Kerr acknowledges that, if Professor Bradley's identifications prove valid, it will probably be found that all the Huronian rocks except those of the middle and eastern belts will prove to be Silurian. Of these he remarks (*l. c.*, p. 140): —

"But this conclusion will not involve the great middle and eastern belts which must still remain Huronian, until determined independently to belong to a later series; both because they are widely separated from the others, and because they have lithological and stratigraphical characters of their own, which would prevent their following any determinations of horizon for the others, which should be based on these considerations alone."

In regard to an area adjacent to Tennessee, Professor Kerr says (*l. c.*, p. 139): —

"This belt of rocks is colored on the map throughout like the other Huronian belts, and for the same reasons, viz.: that they succeed the Laurentian, and differ from them strongly in degree of metamorphism and general lithological character, so that the transition from one to the other is obvious along the whole extended line of contact, and that they have yielded no fossils, which alone could authorize their reference to a later age. And although the fact of unconformability can not be asserted for any one of the sections, this may arise from the circumstance that the disturbance and dislocation of the strata along this line are extreme, and that no detailed or minute examination has ever been attempted, and of course nothing short of such examination would suffice in such a region. And another circumstance of weight is the immense body of these rocks, which must be allowed, on the French Broad for example, after every reasonable reduction for folding, a thickness of several miles. Add these to the primordial or the lowest members of the Lower Silurian, and they receive a most incredible development downwards, since the rocks along the Tennessee border referred to this horizon have already a very great thickness. However, as stated above, these rocks have only been located *provisionally*. And it is right to say further that the only examination I have made of this western Smoky belt, was a mere reconnoisance, mostly on horseback, made in a few weeks in the autumn of 1866."

In 1878 Dr. Hunt referred part of the gneisses of North Carolina to the Laurentian, but found "indications of a belt of Huronian schists," while the "thin bedded gneisses with highly micaceous and hornblendic schists," which Professor Kerr had regarded as Laurentian, he referred to the Montalban.

It results quite clearly from the study of what has been published by Professors Kerr and Bradley, that there has been no satisfactory reference of any of the rocks of North Carolina older than the Triassic to their proper place in the geological series. Professor Kerr's Laurentian and Huronian include all the existing stratified formations in that State below the Trias, and, judging from what is known of the geological structure of the Appalachian belt farther north, it is highly probable that Professor Bradley was right in referring a considerable portion of the metamorphic rocks of North Carolina to the Palæozoic. At all events, it is safe to say that, with our present uncertainty in regard to the geological age and structure of the region in question, there can be no reason for dividing the older rocks into Laurentian and Huronian other than on purely theoretical grounds.

SOUTH CAROLINA.

But little is known in regard to the older crystalline rocks of South Carolina. Mr. Lieber, the former State Geologist, describes different varieties of them; but he gives no clue to their geological position, and but little information is afforded as to their order of succession. Dr. Hunt, however, has endeavored, on the basis of Mr. Lieber's description, to range the various rocks of this State within the systems described by him as occurring farther north. He says (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 10, 11):—

"It is easy, from the reports of Lieber on the geology of South Carolina, to identify in this State the two types of the Green Mountain and White Mountain series. The former, as described by him, consists of talcose, chloritic, and epidotic schists, with diorites, steatites, actinolite-rock, and serpentines. . . . . The great gneissic area of Anderson and Abbeville districts is described by Lieber as consisting of fine-grained gray gneisses, with micaceous and hornblendic schists, and is cut by numerous veins of pegmatite, holding garnet, tourmaline, and beryl. These rocks, which have the character of the White

Mountain series, appear, from the incidental observations to be found in Lieber's reports, to belong to a higher group than the chloritic and serpentine series, and to dip at comparatively moderate angles."

We have not been able to find in Mr. Lieber's reports any evidence that the gneissic rocks of Abbeville and Anderson districts were considered by him as newer than the chloritic and serpentine series. On the contrary, the granites and gneisses are again and again stated to be the oldest rocks in the State.

GEORGIA.

In Georgia, according to Dr. George Little, the State Geologist, there are no Azoic rocks; but Dr. Hunt on lithological grounds referred some gneisses (granites) to the Montalban, and some slates probably to the Taconian.

TEXAS.

Mr. S. B. Buckley, State Geologist, in his various reports, describes various forms of eruptive, crystalline, and metamorphic rocks as occurring in that State. In his First Annual Report he defines the Azoic as follows: —

"The Azoic are igneous rocks, destitute of animal and vegetable matter, thrown up from below, or rocks altered by contact with such melted matter. . . . . Some of the Azoic rocks are the oldest known, and others not, for there are granites in Texas, ... which have been thrown up during the formation of the rocks of the older Silurian." (*l. c.*, pp. 15, 16, 76.)

In his Second Report, Mr. Buckley recognizes two distinct ages — the Azoic and the Eozoic — as forming "Archæan time." In the Azoic he includes the granites and their associated rocks destitute of fossils; viz. shales, mica schists, gneiss, hornblende, porphyries, etc. There are said to have been two or more periods of the upheaval of the granites, one probably later than the Cretaceous.

Since it is so evident that Mr. Buckley under the head of Azoic includes rocks of very different ages, it will not be necessary for us to

dwell at large upon his work, which is of no importance in reference to the question before us. The views he appears to hold with regard to the eruptive and older stratified rocks in general are quite analogous to those of Prof. C. H. Hitchcock, which have already been presented, as well as to those of the geologists of the Fortieth Parallel Survey, to which reference will be made a little farther on.

TENNESSEE.

Prof. J. M. Safford, in his first Report on the Geology of Tennessee, 1856, referred the metamorphic rocks of the State to the Azoic, separating them into two series: the semi-metamorphic, and the metamorphic. In the Final Report (1869) the metamorphic rocks were regarded as Azoic or Eozoic; but he states that they can be traced in part to unmetamorphosed beds, and from what follows it will be seen that he regarded them as in part formed from and in part conformably underlying the Ocoee group, which he referred to the Potsdam. He says of the metamorphic rocks of the State: —

"With reference to age, I have no reason for believing that this group, within Tennessee, includes the metamorphosed beds of any formation of more recent date, than the Ocoee Conglomerate and Slates. A portion of the beds are certainly referable to the Ocoee Group; the remainder, although conformable, may be older, and most likely are. There are sections which show clearly the change of the conglomerate, and its associated rocks, into gneiss and mica, and other slates. In approaching, for instance, the Ducktown region, from the west, the pebbles of the conglomerate gradually lose their forms, becoming more and more, small, shapeless masses of quartz, and yet discernible, even when the gneissoid or complete metamorphic character is seen. In the northern part of the State, at many points, the passage of the Ocoee beds into gneiss, is gradual and apparent. A considerable part, indeed, of our metamorphic rocks, can be, I think, thus referred to these beds. The question as to the greater age of other parts, is not so easily settled, and must remain open for the present. I know of no sufficient reason for referring any of these rocks to the Huronian or Laurentian series of Canada." (*l. c.*, pp. 177, 178.)

Prof. Frank H. Bradley holds that all the metamorphosed rocks in Tennessee were Silurian. (Am. Jour. Sci., 1875, (3) IX., pp. 279–288, 370–383.)

ARKANSAS.

It appears that Dr. David Dale Owen regarded the crystalline rocks of Arkansas as eruptive, stating that the sedimentary rocks have been shattered, uptilted, and broken by them. He also gives localities in which they overlie the slates. His evidence, what there is of it, would indicate the correctness of his views, but it is far from being as complete as would be desirable.

MISSOURI.

There is no published evidence showing that the crystalline rocks of Missouri proved to be older than the Silurian are of different ages, or that most of them are not eruptive. They have been assigned to the Laurentian and Huronian, but solely from their lithological characters.

MICHIGAN AND WISCONSIN.

A short time ago a discussion of the various theories regarding the crystalline rocks of the region adjacent to Lake Superior, and especially its southern shore, was published by one of the authors of the present paper.* In that work the evidence by which the theories in question have been sustained was pretty thoroughly examined, and it now remains, therefore, only to add that which is necessary in order to bring the discussion down to the present date. Some little repetition and recapitulation will, however, be advisable, in order that the reader of this paper may have a clearer idea of the points here discussed.

The copper-bearing rocks of Lake Superior have been considered by some geologists as a distinct formation, older than the Potsdam sandstone adjacent to which it lies. The principal evidence in support of this opinion was supposed to have been obtained at the falls of a branch of Torch River, known by the name of Douglass Houghton. Here the

* Notes on the Geology of the Iron and Copper Districts of Lake Superior. By M. E. Wadsworth. This Bulletin, *ante* [Vol. VII., or Geol. Series, Vol. I.], pp. 1–157.

trappean or cupriferous series was said to end, and to have abutting against its edges strata of the Potsdam. The latter was also said to contain fragments of the other, necessarily older, rock. These facts were thought to prove that the copper-bearing rocks formed a sea-shore bluff, along the base of which the sandstone was deposited with its trappean fragments. In order that the reader may understand the condition of things at that point, it will be necessary for us to indicate the structure of the copper-bearing rocks themselves. They consist of a series of old lava flows (diabase and melaphyr), intercalated between beds of conglomerate and sandstone. The traps are known to be lava flows, by the baking and induration of the immediately underlying rock; by the fact that tongues and dikes extend from the overlying trap down into the rock beneath; by the scoriaceous character of the upper portion of the traps, and the coarser crystallization of their lower parts; by the macroscopic and microscopic evidences of flowing, etc. That they in each case were *in situ* before the immediately overlying rock was deposited, is shown by the facts that they have not affected it in any way, and that they present on their upper surface the irregularities and rounded knobs which lava flows are known to have, especially when exposed to water action; by the presence of rounded fragments of the underlying trap enclosed in the overlying conglomerate; by the absence of fragments of the overlying rock in the underlying one, and by the absence of any marks of intrusion of the traps between different beds.

Sometimes the lava flow was followed by another, without any apparent long exposure of the former; then again the interval between the two succeeding flows was so great, that sandstones and conglomerates having a thickness of from a few inches to half a mile (Marvine) were deposited between them. Of course from this it followed that the surface of the underlying trap suffered denudation, and that afterwards the conglomerate was deposited unconformably upon it. This was the general mode of formation throughout the series on Keweenaw Point. The general condition of things may be correctly indicated by the statement, that in going from the east towards the west the cupriferous series is found to be made up of an increasing number of lava flows and a diminishing number of conglomerates, until a point is reached where the volcanic activity culminated, when the flows diminished and the conglomerates increased, until the Western sandstone was reached. It would follow from the mode of formation, that whenever a sandstone or conglomerate was laid down on the trap, denudation of the latter would take place and fragments of it be enclosed in the uncon-

formably overlying detrital rock; and this would hold good not only of the intercalated beds, but also of the Western sandstone. All these evidences of denudation would then be merely signs of sequence of time, and not of a difference in geological age. Precisely similar facts may be observed at the present day wherever a lava flow has an opportunity to reach the shore of the sea.

The question, then, whether the copper-bearing rocks are a formation of a geological age older than the Lake Superior sandstone, is to be ascertained, if at all, on the eastern, and not on the western side. It has just been pointed out on what evidence the Eastern sandstone was said to be younger than the traps; but a careful examination of the region in question showed its incorrectness. At the Douglass Houghton Falls the stream passes over a cliff of trap, and then winds through a gorge having high and very steep banks. It was very natural that, in ascending this stream from Torch Lake to the Falls, the hasty observer should be led to believe that the sandstone and conglomerate extend in an unbroken band up to the cliff at the latter locality, and regard it as an old sea-shore bluff. This would especially be the case should he confine his observations to the stream, and not attempt to explore the clayey, slippery, difficult sides of the ravine. The writings of previous observers give no evidence that they did more than to follow the bed of the stream; and they all concurred in stating that the sandstone was horizontal, or nearly so, up to the Falls, at which place the trap was said to be first met. When Dr. Wadsworth examined the locality, in 1879, he not only explored the bed of the stream, but also the bluffs on both sides. These examinations showed that the sandstone and conglomerate were not horizontal, but that they had a gradually increasing dip as the Falls were approached from 5° up to 25°, while on both sides of the stream the traps were found holding the same relations to the sandstone and conglomerate that they have been stated to hold elsewhere in the series. These traps had been masked and concealed by the falling rock and earth; but, on digging, foot after foot of the junctions of a number of the lava flows and their adjacent sandstones were exposed. The flow nearest Torch Lake is about two feet in thickness, lying between two beds of sandstone, all having a dip of 20°. Junctions of these beds and the flow were exposed by excavating along a distance of about twenty feet. The trappean pebbles seen by former observers at the Falls were seen to have been derived from the underlying trap, as they are throughout the entire series, and not from the supposed old sea-shore bluff. In the same way, the sandstone and conglomerate were

carefully followed up by the Hungarian River from Torch Lake, and the same condition of things observed. (*Ante*, pp. 113–116.)

These observations are of a kind to exclude any probability of a mistake; they are clear, and definite. Moreover, they explain the errors of previous observers, and until refuted, if they can be, they conclusively show that the Eastern sandstone and the copper-bearing series are one and the same geological formation, although differing in time sequence. It is a remarkable circumstance, that, while this evidence is so clear and explicit, the more recent writers have carefully avoided any mention of it, but have endeavored to discuss the subject on theoretical grounds chiefly.

It now becomes necessary to follow in greater detail some of the writings of others previous to 1879 and later, owing to the importance claimed for them in the more recent discussions. The first to demand our attention is a paper by Prof. R. D. Irving on the relations of the Huronian, Keweenawan, and Potsdam Series. He states (Trans. Wisc. Acad. Sci., 1873–74, II., pp. 117–119): —

"The conclusions, then, that I would draw are these: —

"1. The Copper Bearing and Huronian Series were once spread out horizontally one over the other, and owe their present highly tilted position to one and the same disturbance.

"2. That subsequently — after a long period of erosion — the horizontal Silurian sandstones were laid down over, and against the upturned edges of the Copper Bearing Series, filling also the synclinal, in Ashland county, which lies between the northward and southward dipping sandstones.

"3. That hence the Copper Bearing Series is more nearly allied to the Archæan, than to the Silurian rocks.

"One fact observed, however, seems at first difficult of explanation on this hypothesis. In Douglas county, as already said, the horizontal sandstones can be traced to their exact junction with the southward-dipping traps. But, in several places, the sandstones present a very remarkable change as the trap is approached. On passing up the gorge of Black River, whose sides are perpendicular exposures of rock over one hundred and fifty feet in height, towards the south, the horizontal layers of sandstone are suddenly seen to change from their ordinary position to a confused mass of broken layers, dipping in every conceivable direction, and increasing in confusion as the trap is approached, until, finally, the whole changes to a confused breccia of mingled trap and sandstone fragments. This appearance is presented along both sides of the gorge, for a distance of 300 feet, and I am assured by my assistant, Mr. E. T. Sweet, by whom all observations in Douglas county were made, that it is certainly due to no mere surface misplacement. The same appearance is presented on one of the other northward flowing streams in Douglas county, on a

much diminished scale however, the undisturbed sandstones reaching within twenty feet of the trap. On all other of these streams, the sandstone is undisturbed. The explanation which first suggests itself to account for these disturbances is naturally, that they were caused by the ejection of the traps through the already formed sandstones. In answer to this it may be said that it is very difficult to see how just such a disturbance as this could have been caused in this way, the sandstones presenting no appearance of baking or other indication of heat, but seeming rather to have been *crushed* by a pressure from the south. Next the trap it is crushed to a confused mass, a little further a few layers of sandstone become distinguishable, still further these are all distinct but broken and pitching in every direction, and finally they grade into regular unbroken horizontal layers. It may also be said that the proofs already given of the greater age of the copper bearing rocks, as compared with the horizontal sandstones are so strong as to necessitate some explanation of these disturbances other than the one just mentioned. The only one that I can offer, is this ; the traps being deep seated are, as it were, independent of the more superficial sandstones, and would, if impelled to move by any force, move independently of them. Now a very slight movement of the traps northward against the sandstones would produce all the phenomena observed. Such a movement is not at all difficult to explain." (See also Am. Jour. Sci., 1874, (3) VIII., pp. 46–56.)

In 1879 Professor Irving adopted, in part, a different mode of explaining the phenomena observed above. He remarks : —

"It appears that at the contact there is in many cases a confused brecciated mass of sandstone and crystalline-rock fragments, some of which are of great size, while in places they become rounded, and the rock passes into the ordinary conglomerate. These peculiar appearances, only in one case reaching to any considerable distance from the crystalline rocks, are to be attributed in the first place to the naturally confused mode of deposition on the cliffy shore of the waters in which the sandstones were originally deposited, but, as I have shown in another place, a slight movement northward of the deep-seated crystalline rocks against the more superficial sandstone would account for much. Another thing tending to confuse would undoubtedly be the chemical action, which, as is well known, is so apt to be set up with unusual energy along the contact of dissimilar formations." (Geol. of Wisc., 1880, III., pp. 17, 307.)

Mr. E. T. Sweet, in his report in the same volume, (p. 337, see also pp. 349, 350,) states in regard to the same phenomena, that "on Middle river, the original lines of deposition have been entirely obliterated, and the very argillaceous sandstone transformed into a transverse cleaving slate, somewhat micaceous." This shows the incorrectness of Professor Irving's statement that the sandstones present "no appearance of

baking or other indication of heat." It seems to us that the phenomena observed can best be explained by supposing that dikes intruded themselves after the sandstone was in position, and it is surprising that observations of a more thorough nature were not made so that the question should have been settled. The fracturing, the upward bending of the layers of sandstone, its induration and metamorphism, are all ordinary occurrences in the contact of intrusive matter with the adjacent rock, and other explanations should not be resorted to until rendered necessary by the facts observed. No such phenomena have been observed in the contact of the Azoic with the Palæozoic rocks in the vicinity of the Great Lakes. In fact, it seems from Professor Irving's own language that he would hardly have adopted the explanation he did, if Messrs. Pumpelly and Brooks had not previously endeavored to sustain the view that the copper-bearing rocks are older than the Potsdam sandstone.

Again, it is not shown that these traps are of the same age as those of Keweenaw Point. The only evidence advanced would be quite as effective to show that many of the dikes in the granites and schists of the Azoic, or even the traps of Nova Scotia, are Keweenawan. Moreover, if a lateral thrust is necessary to explain certain facts seen, the phenomena observed could be as well accounted for in this way on the supposition that the sandstone was traversed by a dike, as by the hypothesis that it was a newer formation abutting against the Cupriferous series.

In another place Professor Irving states : —

"Fortunately, however, we have at hand a more absolute proof than this, of the age of the Keweenawan System, for at the Dalles of the St. Croix river, thirty miles above its junction with the Mississippi, and on the west line of Wisconsin, we find horizontal sandstones and shales, crowded with characteristic Primordial fossils, lying upon the irregular and eroded surface of a Keweenawan melaphyr. The contact is finely exposed, and the sandstone near the junction is full of rounded and angular fragments of the underlying melaphyr. This place was described by Owen, but, so infected was he with the prevalent ideas of intrusive rocks, that he looked upon the melaphyr as the newer of the two, disregarding the overwhelming evidence of direct superposition, of the undisturbed condition of the sandstone, and of the melaphyr pebbles and boulders it contains. . . . . It is evident enough, then, that we have here proof absolute that the Keweenawan series belongs below the base of the Palæozoic column of the Mississippi." (Geol. of Wisc., 1880, III., pp. 23, 24, 339, 396, 397, 423 ; Trans. Wisc. Acad., 1875–76, III., pp. 45–52 ; Owen, Geol. Survey of Wisc., Iowa, and Minn., pp. 164, 165.)

In Prof. T. C. Chamberlin's Report, prepared from the notes of the late Moses Strong, it is stated of the same locality : —

"This locality presents the most clear and unequivocal evidence that the Copper-bearing series is much older than the Potsdam sandstone of our state, so much older, indeed, that there was time for the very extensive wearing down of the former before the latter was deposited." (Geol. of Wisc., 1880, III., pp. 416–419.)

Professor Irving later carried his work into the Michigan region, and thus states the conclusions at which he arrived : —

"The series is older than the Cambrian and younger than the Huronian — the separation from the former being by an intervening disturbance and erosion, and from the latter by an intervening erosion, and possibly also by an intervening folding and alteration."

He further found the acidic rocks, from which most of the Keweenaw conglomerates were derived, in place, and adopted the published view of Dr. Wadsworth (*ante*, pp. 113–122), that these rocks are old rhyolites and trachytes. (Report of the Director of the United States Geological Survey [2d Annual], 1882, pp. xxxi.–xxxiv.) Irving also adopted the theory of a synclinal structure of the region, first announced by Foster and Whitney.

Mr. A. R. Selwyn later claimed that he had not expressed any opinion regarding the age of the trap and sandstone of Lake Superior, forgetting the previous expression of his views that they were Huronian (see *ante*, pp. 106, 108), but gives as the result of his studies in 1882 the view that

"they occupy the geological interval elsewhere filled by those divisions of the great lower paleozoic system which underlie the Trenton group. Various considerations point to the Potsdam and Primordial Silurian (Lower Cambrian) as their nearest equivalents. . . . . They are essentially volcanic, sub-aerial, and sub-aqueous formations, and in every sense analogous to the wide-spread tertiary volcanic rocks of Australia and other regions. The only differences are their greater antiquity and the consequent greater changes and modifications they have undergone through the operation of long-continued metamorphic agencies, disturbance, and denudation ; though these changes are far less than those which rocks of the same age, and to some extent similar origin, have undergone in eastern America and in Britain." (Science, 1883, I., pp. 11, 221.)

It is obvious that these views are identical with those published by Foster and Whitney in 1850. (*Ante*, pp. 76–131 ; see also Science, 1883, I., p. 39.)

Professor Irving in reply to Mr. Selwyn stated that "the copper-bearing rocks underlie unconformably — and with an immense unconformity — a series of sandstones holding Cambrian fossils." He further remarked "that the copper-bearing strata also underlie unconformably the eastern sandstone of the south shore of the eastern half of Lake Superior." He also complains that the evidence of himself, Sweet, and Chamberlin regarding the Taylor's Falls locality had been ignored by others. (Science, 1883, I., pp. 140, 141, 359, 360, 422.)

It was in reply immediately pointed out by Dr. Wadsworth, that the above-mentioned observations had neither been ignored nor denied; but that the trouble was that the Wisconsin geologists themselves had ignored the simplest principles of the geology of eruptive rocks, which they themselves admit these to be. (Science, 1883, I., pp. 248, 249.)

In the mean while Dr. Hunt stated that the

"view of the continuity of the cupriferous series with the Potsdam (St. Mary) sandstone was maintained by Whitney; but Logan, in 1863, put forth strong, and to most minds conclusive, reasons for believing that the highly inclined cupriferous rocks at the east end of the lake pass unconformably below this sandstone." (Science, 1883, I., pp. 218, 219.)

It was then pointed out by Dr. Wadsworth, that

"the evidence advanced by Logan, which Dr. Hunt finds so convincing, was mainly a difference in dip between the traps and sandstones at localities several miles apart; and that all the evidences, as Logan himself says, only '*seem to support the suspicion* that the sandstones *may* overlie unconformably those rocks, which, associated with the trap, constitute the copper-bearing series.'" (Science, 1883, I., p. 307.)

Prof. N. H. Winchell then, in agreement with Foster and Whitney, and with Selwyn, remarked with reference to the statements of the latter: —

"I concur with him in the sweeping affirmation, 'that there is, at present, no evidence whatever of their [the cupriferous rocks] holding any other place in the geological series' than that of the 'Potsdam and primordial Silurian'; and I would also add, that there is much incontestible evidence that they *can hold no other*." (Science, 1883, I., p. 334.)

Later, Prof. T. C. Chamberlin summed up the various reasons for supposing that the Keweenaw rocks were distinct from the adjacent sandstones. They were: the different stratigraphical relations; differences in thickness and in constitution; unconformity; the inherent

consistency of this view; the dynamic simplicity of this view; and the discovery by the United States geologists of a like series in the Grand Cañon of the Colorado. He in no wise meets the direct evidence previously given, that the sandstone and traps are one and the same formation, while his arguments ignore the mode of formation, i. e. they would be of value only if both the eastern sandstone and the copper-bearing rocks were of exclusively sedimentary origin. (Science, I., pp. 453–455.)

Since so much has been claimed for the Taylor's Falls locality, it will be necessary to pay some attention to the connection of this with the known copper-bearing rocks of Michigan. Beginning at the Nemakagon district, some granites and diabases are found on opposite sides of the Nemakagon River. A thousand feet below is more diabase. About 250 yards south is a small exposure; then, about 100 yards west, another. Four miles northeast is to be found a series of diabase ledges extending for a quarter of a mile. About twelve miles northwest of this is a belt

"nearly thirty miles in length, over which are scattered, in comparative profusion bare or slightly concealed ledges. . . . . With two exceptions — viz., a sandstone and a conglomerate — the series is formed of trappean rock, mainly diabase and diabase-amygdaloid."

After passing over an intervening space of about thirty-six miles, diabase and quartz porphyry were met with in the Clam Falls district. From this locality on there is a series of outcrops varying from one fourth of a mile to about five miles apart, extending to the Taylor's Falls region (St. Croix district). (Geol. Wisc., 1880, III., pp. 399–415.)

We see then that these rocks, according to the testimony of the Wisconsin geologists, have been mainly determined on lithological evidence, and that when any outcrop of a diabase or melaphyr was found it was placed without question in the Keweenawan series. Again, these outcrops are widely separated by drift-covered regions, and thus far the Wisconsin geologists have not advanced the slightest proof that the St. Croix diabase is the same as the Michigan lava flows.

Dr. Owen stated in regard to this locality, that the trap had

"forced its way through highly fossiliferous strata, breaking up the beds immediately overlying it, entangling and partially indurating the fragments, without, however, tilting or metamorphosing the adjacent beds in any perceptible degree. The fossils, even of the beds almost in contact with the trap dykes, are in a perfect state of preservation, and the strata themselves have no dip perceptible to the unassisted eye in the hillside where they are exposed." (Geol. Surv. Wisc., Iowa, and Minn., 1850, pp. 164, 165.)

In a foot-note Dr. Owen also states that the remains of the shells can be "detected in fragments enclosed in the trap, and so much altered as to be distinguished with difficulty from the surrounding greenstone." It seems hardly possible that Owen could have made these statements if part of the trap at least was not intrusive in the sandstone.

Mr. J. H. Kloos (Zeits. Deutsch. Geol. Gesells., 1871, XXIII., pp. 417–448; Geol. Minn., 10th Ann. Report, for 1881, pp. 175–200) states that he found the sandstone horizontally overlying the trap, or diabase as we — in agreement with Rosenbusch — should prefer to call it. He also observed a conglomerate made up of the ruins of the diabase; but the relations of the conglomerate to the sandstone were not ascertained.

Prof. N. H. Winchell claims that the sandstone in this locality is not the Potsdam, but belongs to a higher formation. This view he holds on account of the physical characters of the rock, as well as differences in the fossils it contains. (Geol. Minn., 1st Ann. Report, pp. 68–80.) Later, Professor Winchell considered the St. Croix sandstone as belonging to the Quebec group, and as overlying the Potsdam sandstone, to which latter he referred the copper-bearing rocks of Keweenaw Point. (Geol. Minn., 10th Ann. Report, pp. 123–136.)

From what has been given it can readily be seen that Messrs. Irving and Chamberlin have failed to recognize the simplest features of the geology of mixed eruptive and sedimentary rocks; and that the conditions upon which they place so much reliance to prove the correctness of their views are exactly those which occur (excepting the presence of fossils) whenever a sandstone or conglomerate is found intercalated in the copper-bearing series. If their evidence is good, then we have "proof absolute" that the Keweenawan series — the copper-bearing rocks — is composed of as many distinct geological formations as there are beds of sandstone and conglomerate intercalated in them. So far as their yet published work goes, all their evidence has not advanced one step beyond that which was made known thirty-three years ago, and it is strictly in accord with the views of Foster and Whitney as then stated. Were this not the case, there is as yet not the slightest published evidence that the St. Croix traps belong to the copper-bearing series: they may be older or younger, while considerable evidence is given by Professor Winchell to show that the sandstone there is more recent than the Potsdam. Moreover, there is positive evidence that the copper-bearing rocks are part of the Eastern sandstone formation on Keweenaw Point. It seems, then, that the Keweenawan series owes

its origin and perpetuity in part to erroneous observations, and in part to erroneous deductions from correct observations.

Prof. N. H. Winchell, in his Report for 1881, gives a summary of the geological opinions held regarding the copper-bearing rocks, which summary he appears to have made up with additions, but without acknowledgment, from that previously given by Dr. Wadsworth (*ante*, pp. 107–109), using also the more complete exposition of views presented on pp. 76–107. For an authoritative expression of Dr. Wadsworth's views he does not refer to this work (pp. 1–157), which was at that time in his hands, but to a brief abstract only. (Proc. Amer. Assoc. Adv. Sci., 1880, XXIX., pp. 429, 430.)

In the article previously referred to (this Bulletin, pp. 1–76), it was claimed by Dr. Wadsworth as the result of an examination of the literature relating to the Azoic region of Michigan, together with a considerable amount of study both in the field and in the laboratory with the aid of the microscope, that, in accordance with the early published views of Foster and Whitney, the granite was eruptive, as were the greenstones (diabase, melaphyr, etc.), part of the iron ore and jaspilite, the peridotite, etc.; and that these eruptive rocks, united with the sedimentary ones, made up the Azoic system; while there was no evidence existing to show that this formation could be separated into two divisions. It was pointed out that, in the subsequent Survey of the Lake Superior region by Messrs. Brooks and Pumpelly, great ignorance of the simplest principles of geology and lithology had been displayed, and that no confidence could be placed in the results at which they professed to have arrived.*

We now pass to the consideration of some later publications relating to the Azoic rocks of Michigan.

In 1881, the fourth volume of the Report of the Michigan Geological Survey, by Dr. C. Rominger, was published. The author of this Report appears to have known nothing of the work of others, excepting that of

* It might further have been shown that, although Major Brooks professed in his Report to give a history of the scientific exploration of the Iron District of Lake Superior, he entirely ignored the work of Messrs. Foster and Whitney, by whom that region was first geologically mapped, and the important localities of iron ore laid down. It might also have been shown that the geological map of the Lake Superior region published by Messrs. Brooks and Pumpelly was, to a considerable extent, a copy of that of Foster and Whitney, and that not the slightest acknowledgment was made for thus incorporating into their own work the geology of extensive areas which had never been examined with any detail either by themselves or by their assistants.

Mr. T. B. Brooks; consequently numerous statements are put forth by him as original, when in fact they had been previously published by others. Had Dr. Rominger been more conversant with the literature of the district, many errors into which he has fallen would have been spared him, since he is essentially a palæontologist. However, he appears to have worked conscientiously, and to have endeavored to ascertain the truth so far as he could.

Regarding the so-called Laurentian granites, Dr. Rominger states: —

"According to my own observations the granites of Marquette are eruptive masses which came to the surface after the Huronian beds were already formed, and by their eruption caused, not only the great dislocations of the Huronian formation, but the half molten plastic granite masses induced by their contact with the Huronian rock-beds, also their alteration into a more or less perfect crystalline condition, and commingled with them so as to make it an embarrassing task to find a line of demarcation between the intrusive and the intruded rock-masses." (*l. c.*, p. 6.)

He also points to the fact that lamination is no proof of stratification, stating that he had "in several instances seen narrow intrusive granitic dyke-masses similarly laminated by the parallel arrangement of the mica scales in them." (*l. c.*, p. 16.)

Dr. Rominger further proceeds: —

"The granites, considered in their present surface position, are, in relation to the stratified sedimentary rocks of the Huronian series, actually the younger rock, so far as the intrusion of very large masses of granite between the stratified sediments can be demonstrated by clearly observable facts, and as the other larger bodies of granite inclosing them [the so-called Huronian schists] from two sides are in direct continuity with the vein granites, and lithologically identical with them." (*l. c.*, p. 22.)

While Dr. Rominger regarded part of the basic rocks as truly eruptive in the form of dikes and lava flows, he recognized also the intrusive nature of much of the remainder; but being unable, from lack of lithological training, to distinguish between the older eruptives and their associated schistose rocks, he — like Mr. Brooks — confounded them together, and adopted for explanation the following theory, difficult of comprehension, and certainly not at all consonant with the facts observed in the district, the difficulty lying with the observers, and not with the rocks: —

"From such a standpoint, the various crystalline hornblende rocks found in association with the granites could be considered as remelted, completely metamorphosed, Huronian sediments, on account of their nearest proximity to

the volcanic focus, while those more remote from it did not altogether lose their sedimentary structure, but still became altered, and frequently streams of the lower melted or emolliated plastic masses broke through them, filling transverse ruptures or entering between the ledges parallel with the bedding." (*l. c.*, p. 23.)

The rocks thus united Dr. Rominger classed as the "Dioritic Group." He showed, as Dr. Wadsworth had already done, the incorrectness of Major Brooks's work, and how little reliance could be placed on his conclusions.

Dr. Rominger appears to have found in the Menominee iron region a condition of things very similar to that existing in the Marquette district, and arrived at similar conclusions. (*l. c.*, pp. 240, 241.) His idea that the Marquette and Menominee schists are Huronian means nothing beyond this, that they appear to him to be lithologically similar to the rocks called Huronian in Canada; while — so far as his actual work goes — he reaches conclusions regarding the relation of the granitic and schistose rocks identical with those advocated by Foster and Whitney thirty years before. The result of Rominger's work is decidedly opposed to the division of the Michigan Azoic into two or more formations.

The question of the origin of the iron ores was not only discussed in the previous portion of this Bulletin, but also elsewhere. (Proc. Bost. Soc. Nat. Hist., 1880, XX., pp. 470–479.) The following indorsement of these views, with permission to publish it, was received from Mr. A. R. C. Selwyn: —

"I believe with you that many of our great Archean iron-ore beds are of eruptive origin, while others are stratified iron-sandstones, analogous to those which are now forming along the northern coasts of the St. Lawrence Gulf by the combined action of the rivers and the waves on the more ancient (probably eruptive) ore beds. But such magnetic ores always contain from 40 to 50 per cent of insoluble matter (probably chiefly silica), a much larger proportion than those which are presumably of eruptive origin."

Professor Dana, in opposition to the view of the eruptive origin of the iron ore and jaspilite, claims that conformability is the evidence used principally in deciding that the ores and schists are alike in their mode of origin. He also attempts to decide the point by appeals to other regions. It seems to us that the origin in each region is to be proved by the study of the district itself, and that arguments from analogy when used alone are fatally defective.

The question of conformability was the one examined, and upon which the decision regarding the origin of the iron ore was made. A

careful examination of the literature showed that there was no published evidence of more than a superficial study of the relations of the ore to the associated schists; but all was based on theoretical views. Now the examination described previously was made for the express purpose of determining the relations of the ores and schists, without regard to any one's views. It showed that — wherever their relations could be determined — they were those of an eruptive rock in contact with a sedimentary one. These things were described and figured, and no one has yet attempted to meet the evidence, either to deny it or explain it away.

Two other attempts to discredit this view, besides that of Dana, were made. One was by Prof. J. S. Newberry, who, being evidently unable to meet the evidence given, contented himself by remarking that "to be asked to believe that the ore sheets are intrusive is a greater strain upon my credulity than it can endure." In other words, he takes especial pains to show that scientific questions are with him merely a matter of theoretic belief, and not one of evidence and facts. ("The Genesis of our Iron Ores," School of Mines Quarterly, Nov., 1880, p. 8.)

The second attempt was made by Dr. A. A. Julien, who likewise ignored the evidence, and confined himself to saying, "The mineralogical constitution and infusibility of these ores, their distinctly sedimentary lamination, etc., clearly testify to the unsoundness of these hypotheses." (Proc. Phila. Acad. Nat. Sci., 1883, pp. 335–346; Trans. N. Y. Acad. Sci., 1882, II., pp. 6–8, 13–17.) If these ores are regarded as an extrusion from the molten interior of the earth, their mineralogical constitution and infusibility have no bearing upon the question; but, on the other hand, if they are of sedimentary origin Dr. Julien must explain how it was that later they became plastic, so as to become intrusive, as they plainly are. That they are distinctly sedimentary in their lamination, or that the jaspilite is a fine silicious sand, we deny. Messrs. Julien and Newberry both show in their writings that they have not made themselves acquainted with the mode of occurrence of the Marquette iron ore, either by observations in the field, or by study of the published descriptions. Dr. Julien's paper is especially replete with errors.

Passing now to the Azoic rocks of Wisconsin we find that in 1876 Mr. E. T. Sweet pointed out a supposed unconformability between the Laurentian and Huronian at Penokee Gap, stating (Trans. Wisc. Acad., 1875–76, III., pp. 43–44): —

"When the railroad cut is completed at this locality, the absolute junction of Laurentian and overlying Huronian will doubtless be exposed. There can

be no doubt of the unconformability of these formations, approaching each other as they do with a persistent opposite dip and somewhat different strike. Unconformability has been shown to exist between the Laurentian and Huronian in Michigan, but this is the first time it has been proven in Wisconsin."

Of the same supposed unconformability at Penokee Gap, Prof. R. D. Irving remarks (Am. Jour. Sci., 1877, (3) XIII., p. 308):—

"The crystalline rocks of Wisconsin include unquestionably two distinct terraces, the one lying unconformably upon the other, as is beautifully shown at Penokee Gap, on Bad river, in the Lake Superior country. Here a white siliceous marble of the Huronian, overlaid by hundreds of feet of distinctly bedded slaty rocks, and dipping northward, is to be seen within twenty feet of large ledges of dark colored amphibolic gneiss, whose bedding planes dip southward and strike in a direction diagonally across that of the more northern beds. There are no doubt instances where the two series are difficult to separate, similar rocks occurring in both groups, but the existence of the two is incontestable."

In the third volume of the Geology of Wisconsin (pp. 94, 98, 108, 116, 117, 248–250) accounts of the unconformability of the Laurentian and Huronian are given, but the kind of contact when seen was not observed. But if the Laurentian rocks are eruptive, then of course there would be unconformability. The proof advanced was, that the foliation of the granite and gneiss dipped at a different angle from that of the Huronian rocks. Here, as in the case of the Keeweenaw series, the Wisconsin geologists failed to take into account the conditions necessary to prove their points; while Professor Irving, without giving any evidence of value, made out a beautiful fault — on paper — at the Penokee Gap. So far as can be judged from the evidence presented by these geologists, it appears that they have in Wisconsin the same structure as exists in the Azoic of Michigan, namely, a series of mixed sedimentary and eruptive rocks.

From the following extracts it will be readily seen that there are no other than lithological grounds for assigning these rocks to the Huronian and Laurentian: that they are two distinct formations they entirely fail to prove.

Major T. B. Brooks states (Geol. of Wisc., 1880, III., p. 468):—

"No rocks affording to me the slightest suggestion of a conglomeritic structure have been found in the Laurentian system, its rocks being always highly metamorphosed, and often so much so as to destroy all traces or suggestions of bedding."

In the same report (p. 531) Mr. Brooks also points out several areas of granite in which this rock was found to be intruded into the supposed

Huronian. There seems not the slightest reason to regard this as anything different from the so-called Laurentian granite, and this strengthens the probability of the view that the so-called Laurentian granite is really eruptive in the so-called Huronian. (*Ante*, pp. 22, 70, 71.)

In 1880, Professor Irving gives as the reasons for assigning the rocks which are placed in the Laurentian in Wisconsin to that system, their

"close lithological similarity — the only marked difference being the absence of crystalline limestones in the Wisconsin area — of similar structural relations to the Huronian, Keweenawan, and Lower Silurian systems, and of probable direct continuity with the Canada Laurentian through the upper peninsula of Michigan and underneath the waters of Lake Superior." (Trans. Am. Inst. Min. Eng., 1880, VIII., pp. 480, 481.)

Of the Huronian in the same article it is stated (p. 483): —

"The rocks of this series have been called Huronian by Brooks, and, in the writer's judgment, correctly so, on account of their similarity to the Canada Huronian, with which they not improbably have a direct connection underneath the Silurian of the eastern part of the peninsula, but more especially because they evidently occupy the same geological interval as the typical Canadian series, exhibiting the same non-conformity with an underlying gneissic and granitic system."

It appears, then, that the only evidence that the Wisconsin geologists have that the Laurentian and Huronian are what they purport to be is lithological; and they have advanced no sound argument showing that they form distinct ages in the Azoic System. The relation of the two supposed series is not that which is seen when the Palæozoic comes in contact with the Azoic, or what it would be naturally were the Huronian laid down on the pre-existing Laurentian. The contacts — when these contacts have been figured — appear rather to be those made by eruptive rocks with prior existing ones. The geologists before mentioned have assumed, not proved, the sedimentary metamorphic origin of all the rocks in question, and on the correctness of that assumption depends their argument. They have failed to observe the phenomena of the contact, when seen, beyond the mere fact of a different dip to the foliation observed. In fact, they have failed to prove any of the points essential to establishing their conclusions.

Later, Irving advanced, as if original with himself, the view that the so-called greenstones or diorites of the Marquette district were eruptive, and that the hornblende was secondary after augite. This too when the portion of this Bulletin relating to the Iron and Copper districts of Lake Superior (*ante*, pp. 1–157) had been sent him, in 1880, at his own

special request. Although professing to indicate the microscopic work which had been previously done, he ignores completely that given in the pages before mentioned, which anticipated him in almost every point. (Am. Jour. Sci., 1883, (3) XXVI., pp. 27–32, 155.)

In 1866 Prof. James Hall referred some gneiss and granite on the Redwood River to the Laurentian, and some quartzites in the valley of the Minnesota River to the Huronian. This was done solely on lithological grounds, while the two series of rocks were not seen together. (Trans. Am. Phil. Soc., 1869, (2) XIII., pp. 329–340.)

It would seem that Dr. F. V. Hayden held that the quartzite was most probably supra-Carboniferous, Triassic, or possibly Cretaceous. This was on account of fossils which were found in some quartzite in the adjacent region. (Am. Jour. Sci., 1867, (2) XLIII., pp. 15–22). Part of Professor Hall's views were regarded as untenable by Prof. N. H. Winchell. (Bull. Minn. Acad. Sci., 1874, pp. 100, 101.)

In 1872 Prof. N. H. Winchell divided the "granitic and metamorphic rocks" extending across Minnesota from the northeast to the southwest into Laurentian and Huronian; on what grounds does not appear. (Report on the Geological Survey of Minnesota, 1872, pp. 64–67.)

In 1880, in the Report of the Geological Survey for 1879 (p. 26), Professor Winchell remarks: —

"We hence see the Potsdam in its extension to Duluth involved with these igneous rocks, in upheaval and metamorphism, and cannot resist the conviction that the whole series known as the Upper Copper Bearing Rocks, or as the Keeweenian, or as the Quebec Group, on different authorities, was correctly assigned to the Potsdam at first by Messrs. Foster, Whitney and Hall in 1849, and subsequently by D. D. Owen."

The evidence on which he relies in making this statement is the fact that the copper-bearing rocks at Duluth are seen to be continuous with, and to form part and parcel of, the Potsdam sandstone as it extends from that point into Wisconsin. This view of Professor Winchell's harmonizes with that which has already been shown by us to exist in Michigan. The Minnesota geologists have not furnished any evidence, other than that based on lithological resemblances, to uphold the division of the Azoic system into the two series Huronian and Laurentian. Moreover, it seems to be the fact that in this State, as well as in Michigan, the supposed Keweenawan is nothing more than Potsdam.

THE FORTIETH PARALLEL SURVEY.

The results of the Fortieth Parallel Survey, in so far as the geological and lithological investigations are concerned, will be chiefly found in the first, second, third, and sixth volumes of the series of publications of that Survey. These volumes will be referred to in the following pages simply as I., II., III., and VI.

The first of these, in the order of publication, is Volume III. This bears the title of "Mining Industry," and is chiefly devoted to practical matters connected with mining and metallurgy. It is therefore of minor importance to us in connection with our present inquiry.

The second in order is that of Professor Zirkel, Volume VI., bearing the date of 1876. This volume is devoted to setting forth the results of a microscopical examination of the lithological collections of the Survey. The next is Volume II., containing the descriptive geology, by Messrs. Emmons and A. Hague. This volume comprises the whole geological work of the Survey, discussed in a geographical order. It bears the date of 1877 on the title-page. Volume I., by Mr. King, entitled "Systematic Geology," was issued last of all, in 1878. It contains, as its title imports, a systematic discussion of all the geological, lithological, and chemical investigations of the Survey, treated in chronological order, or in that of the geological age of the formations. In the present necessarily brief examination of that part of the work of the Fortieth Parallel Survey which is connected with the subject of the present paper, the relation between Volumes I. and II. should be borne in mind, and will be best understood on reading the following statement by Mr. King: —

"The purpose of this volume [I.] is to present, as briefly as possible, a systematic statement of the data collected, and the induction we have been able to make. In Volume II. will be found a continuous description of the geological facts observed, treated geographically. . . . . *Whoever wishes to know the structure and details of given features should consult that volume.*"

In the first place it will be noticed that Mr. King begins his volume with the consideration of what he calls the "Archæan." Nothing being said in the way of defining what is meant by this term, it would naturally be supposed that it was employed with the same meaning as that intended by Professor Dana,* by whom the name Archæan was intro-

* See, in reference to this point, farther on, page 547.

duced into geology as the equivalent of the Azoic of Foster and Whitney. By them this latter term was used to designate the rocks which had assumed their present position prior to the deposition of the lowest member of the Lower Silurian.* Thus, for instance, in accordance with this view, granite erupted after the Jurassic epoch could not be called Archæan. It does not appear, however, that Mr. King had this idea clearly present in his mind while writing the volume in portions; at least, this is the result to which an examination of the work leads us. In fact, at the beginning of the chapter headed "Archæan," he says: —

"At intervals over the whole mountainous area west of the 100th meridian, masses of gneiss or crystalline schists, with their associated marbles, dolomites, and quartzites, and eruptive bodies of granite, porphyries, gabbros, &c., are found to underlie more recent strata."

The rocks here mentioned he then immediately proceeds to designate as "these Archæan bodies," without any limitation as to their geological age.

In order, therefore, that we may ascertain how far there is evidence justifying the calling of these various "bodies" Archæan, according to the original geological meaning of that term, it is desirable that we should take up some of the more important regions where this "Archæan" occurs, and examine briefly the evidence by which its geological age has been established.

The first supposed Azoic (Archæan) rocks with which we have to do are those of the Colorado (Laramie) Range. The rocks of this range are granites and gneisses, with a very little mica schist (I., p. 22). It is evident that Messrs. King, Emmons, and Hague in general regard as a gneiss any granitoid rock which possesses in the slightest degree a parallel arrangement of its constituent minerals. It is also evident that in most cases they call this condition stratification.

Regarding this range we find no proof advanced that the granites and gneisses are stratified, and not eruptive, except the foliation above mentioned. Since it may be claimed by some that Professor Zirkel by his microscopic observations proved these and other granites to be of metamorphic sedimentary origin, it is perhaps well to look at his evidence. He distinctly states (VI., p. 59) that the diagnostic characters that he has given as distinguishing metamorphic, older eruptive, and younger eruptive granites from one another, "are valid only for the examined rocks of the Fortieth Parallel, and that it is not allowable to generalize from them for other countries." From this it is evident that these

* See Dana's Manual of Geology, 2d ed., 1875, p. 148.

characteristics were not the result of any previous study, but solely of the investigation of these particular rocks. Since Professor Zirkel never studied the rocks of the Fortieth Parallel Survey in the field, and since these diagnostic characters were obtained from those rocks only, how was it possible for him to know which were metamorphic, which older eruptive, and which younger eruptive granites?

Mr. King states that the supposed Archæan rocks were proved to be of that age, not only by their lithological characters, but also by their being seen in contact with the Potsdam and some presumably Cambrian rocks. These contacts were not within the limits of the Fortieth Parallel Survey, and he gives us no information in regard to their characters. (I., p. 21.)

Mr. Hague's statement, however, goes to show that in point of fact these rocks were upheaved in some parts since the Triassic; in others, since the Jurassic; and in others, since the Cretaceous (II., pp. 6–93). This demands that one of two theories should be adopted; either that these rocks were pushed up in a solid body, or that they were eruptive. In the former case, they are regarded as ancient land bodies, about which the later formations were deposited, all being subsequently uplifted by the granite upthrust. We fail to find any evidence in the publications of the Survey that examinations were made to see if the later formations (except the Tertiary and Cretaceous) contained *débris* from the supposed Azoic (Archæan); or to ascertain whether the contacts were those of one rock laid down upon another, or eruptive, or such as would naturally occur in case a solid mass was thrust up through another. In fact, no evidence in regard to these points is adduced, except the statement that the supposed later formations lie unconformably against the Archæan, which unconformability would exist in any of the before-mentioned cases. Had evidence been seen, we cannot imagine it would have been passed over in silence. So far as this district is concerned, the oldest rocks in contact with the granitic rocks are of Carboniferous age. The supposed Azoic rocks are considered to be Laurentian on the strength of lithological resemblances, and they are also said to constitute one formation. In the district in question, however, it is impossible to prove them to be older than the Carboniferous; and by neglecting to give the evidence, if any existed, they are not shown to be older than the beginning of the Cretaceous. (I., p. 299.)

The gabbro of this range, which, according to Dr. Hunt, has the characters of the Norian (Proc. Bost. Soc. Nat. Hist., 1878, XIX., p. 276),

Mr. King says is eruptive through the granites (I., p. 27), while Mr. Hague makes the same statement (II., p. 13). If this gabbro is Norian, and Mr. King is correct in stating it to be eruptive through the Laurentian granites, it follows that the Norian formation is older than the Laurentian; or else that the supposed Laurentian granites are not of that age, — that is, if we are to accept the theories of Dr. Hunt and some of his followers: he, however, holds that the granite (gneiss) of the Colorado Range is Laurentian. (*l. c.*, p. 276.)

The Medicine Bow Range is referred by Mr. Hague, "with considerable hesitation," to the Huronian, and this reference is said to be "based entirely upon lithological evidences." Part of the rocks are sedimentary; but a large portion regarded by Messrs. King and Hague as sedimentary has not been proved by them to be so. The question still remains, therefore, How much of the supposed Huronian characters is due to eruptive agencies and their concomitants, and how much to geological age? The evidence advanced by Mr. Hague shows that the upheaval of the range was not completed until at least as late as the Cretaceous epoch, while, in fact, no proof is given that it is older than Tertiary. It was seen in contact with no rocks known to be older than the Triassic, although beds supposed to be of Carboniferous age were observed in one locality. The kind of contact formed by these Huronian rocks with the supposed later ones was not noted; neither do we have any information given that *débris* from the Huronian were found in the other formations, until high up in the Tertiary. Had such *débris* been observed it unquestionably would have been mentioned, since not only here, but in the Colorado Range, the occurrence of such material is noticed in the Tertiary.

The supposed Huronian formation has not then been proved to be older than the beginning of the Tertiary, and in the present state of geological science it is impossible, if the age of the other formations has been correctly determined, to prove it older than the Carboniferous. We do not find any evidence given that the uplift of the Park Range took place prior to the Cretaceous; there being here the same absence of proof as was indicated in the case of the two preceding ranges. In this case, however, no rocks older than the Triassic were found in contact with the supposed Archæan, and yet the range — on lithological grounds, purely — is assigned to the Laurentian. The evidence in regard to Rawling's Butte seems to be the same as that relating to the Park Range, through the Archæan schists of which Mr. Emmons remarks that basalt is seen to have been erupted.

The next series of supposed Archæan rocks is in the Uinta Range. The rocks there, according to Mr. King, are quartzites and hornblendic and hydro-mica schists. Another quartzite unconformably overlying it, and said to contain fragments of the Archæan (I., p. 154), is referred with doubt to the Carboniferous. In some places the Archæan gives evidence of having been uplifted since the Fox Hill Cretaceous (II., p. 268). Mr. Emmons, it seems, would refer these rocks to the Huronian on account of their lithological characters.

The Wahsatch Range was regarded as the type of the Archæan (Azoic) exposures in the district covered by Mr. King's survey. It is, however, more difficult to make out from the writings of Mr. King and his coadjutors what they believe its history to have been, than it is to learn their ideas of any of the other districts within their field of exploration. It would also seem that in some places their views regarding the origin of the granites, and the geology of the Wahsatch Range, in general, had decidedly changed during the time which elapsed between the publication of Volumes VI. and I.; Volume II. representing the later transition period, with a still greater change since Volume III. was published. In order to give some idea of the views of Messrs. King, Emmons, and Hague, it is necessary to quote to some extent from their writings, as well as from Volume VI.

At the time of the publication of Volume III. (1870), it seems Mr. King held that the granites were all of eruptive origin, and of Jurassic age; while the stratified rocks in his district were regarded as conformable from "the early Azoic up to the late Jurassic period." In that volume Mr. King says (III., pp. 2, 3) of the region covered by his Survey: —

"The greater part of the rock is a series of conformable stratified beds, reaching from the early Azoic up to the late Jurassic period, when these level beds were compressed into vast mountain corrugations and elevated above the sea in a general, wide, and high plateau. Accompanying the upheaval and crumpling of this great oceanic family, and bursting from its fractured folds, are important masses of granite, penetrating the axes of the flexures and breaking through lateral fissures. Quartz-porphyries, felsite rocks, and notably syenitic granite, with occasional occurrences of granulite and greisen, accompany the ejections of granite. The date of their orographical period is assigned to the late Jurassic on grounds which will be found fully discussed in the first volume of the present series. . . . . This Exploration has demonstrated that all the parallel ranges of the Great Basin, including the chain of the Wahsatch, its eastern wall, belong to the same system [Jurassic] of upheaval."

Not only were the grounds on which the Jurassic age was assigned to the granite not subsequently discussed, but in point of fact an entire change of view took place previous to the publication of Volume I., the reason for this absolute reversal of opinion in regard to a fundamental point in the geology of the Cordilleras being nowhere given, and — what is still more inexplicable — no allusion being made to it.

Mr. Emmons, in describing part of the same range (the Wahsatch), states (II., pp. 355, 360–363, 365) : —

"A body of Archæan slates and granite is surrounded, and partly covered, on all sides except the west, by a conformable series of sedimentary rocks, of an aggregate thickness of over 30,000 feet, extending in age from the Cambrian to the Jurassic inclusive. The granite mass, though eruptive, has not been protruded through this immense thickness of overlying rocks, but their beds were deposited around and over a submerged mountain-range of granite surrounded by Archæan rocks ; and subsequent elevation, flexure, dislocation, and erosion have produced the conditions represented on the map, where it will be seen that of this conformable series, now bent and twisted, different horizons from the Cambrian up to the Middle Coal Measures are at different points in contact with the granite body. Of the immense arch which once covered this body, the western half has been faulted down, while the top of the arch, with its thickness of 30,000 feet of rock masses, has been broken up and worn away by atmospheric agencies. . . . . In Big Cottonwood Cañon, ... is a small exposure of granite. . . . . It is difficult to say whether this rock should be considered as part of the main granite body, which it does not resemble very closely, or with the later outbursts of granite-porphyries and diorites, which are found intersecting the sedimentary rocks of this region. These dikes of porphyry and diorite are very frequent, especially around the Clayton Peak mass and in the region where the mineralization of the beds has been most developed. . . . . Near this granite or diorite body of Big Cottonwood Cañon, in one of the beds of the upper part of the Wahsatch limestone, is a dike about 20 feet wide, of syenitic granite-porphyry, so classed by Zirkel, which resembles the granite in general appearance. . . . .

"The Palæozoic beds of this region, which fold around and partly cover the granite body, have been subjected to intense compression and local metamorphism, twisted and contorted in every direction, faulted and dislocated, and penetrated by intrusive dikes and mineral veins. . . . . The great belt of Wahsatch limestone, which forms the main stratigraphical landmark in these formations, ... forms massive cliffs at the southern head of Little Cottonwood, and here already, in the mantling of white, through its general blue color, shows the commencement of the metamorphism which has marbleized its beds in great degree from here to the mouth of Mill Creek Cañon, where they disappear beneath the Salt Lake plain. This belt includes, as has already been stated, the three groups of Lower Coal-Measures, Sub-Carbon-

iferous, and Nevada Devonian. . . . . Between Little Cottonwood and American Fork . . . . all these beds standing at high and varying angles, and being much broken and contorted."

In Volume I. Mr. King remarks (pp. 44–48) : —

"The Archæan rocks in the explored portions of the Wahsatch are exposed at intervals along the west front of the range for nearly 100 miles, and are composed of granites, garnet rocks, aplitic schists, and a very extended series of gneisses and hornblendic schists, with subordinate quartzites. The manner of their exposure is of very great interest, involving the most extensive dynamic action observed within the limits of the Fortieth Parallel Exploration. The chain of out-crops clearly represents an old Archæan range of bold configuration, which has been buried beneath an enormous accumulation of Palæozoic and Mesozoic sediments. It was this buried Archæan range which controlled the position and direction of the modern Wahsatch Range. After the uplifts took place, and the Palæozoic and Mesozoic strata were thrown into their present inclined position, a great longitudinal fault occurred throughout this whole portion of the range, by which the entire western half of the ridge was thrown downward from 3,000 to 40,000 feet, and is now entirely buried beneath the Pliocene and Quarternary formations of the Salt Lake basin. The present abrupt west front of the Wahsatch is the standing face of this great fault, and here the Archæan rocks are seen to occupy the core of the range, unconformably underlying the Palæozoic series, and rising to different stratigraphical horizons in the overlying series. In the southern portions of Map III., in the region of Cottonwood and Little Cottonwood cañons, is exposed an approximately conformable series of 30,000 feet of Palæozoic strata, overlying the granite and schists which there together form a portion of the early Archæan surface. The origin and nature of the granites at this point are obscure. There seem to be two distinct types — a granitoid gneiss, having a decided stratification, and an apparently eruptive body, which possesses in an interesting degree the conoidal structure so prominently developed in the granites of the Sierra Nevada. About fifteen miles south of Salt Lake City the Palæozoic beds are thrown into a broad semicircular curve, having a convexity to the east and a varying dip always away from the centre of this curvature. The ends of the strata of this great flexure advance westward until they approach the region of the great fault, their eroded edges forming the foot-hills of the range. The centre and nucleus of this immense curvature is a body of Archæan rock, composed partly of schists, but principally of a great central mass of granite and granitoid gneiss, having its best exposures in Little Cottonwood Cañon and the peaks to the south, and again in the Clayton's Peak mass, where it rises like an island through the strata of the Lower Coal Measure limestone and the Weber quartzite. . . . . Although in Clayton's Peak, and again near the lower end of Little Cottonwood Cañon, the rock possesses all the physical habit of a truly eruptive granite, and although in the Clayton's Peak region the granite has undoubtedly been a centre of local metamorphism

and of metalization, yet, from the position of the overlying strata, a preponderance of evidence points to the belief that, whether eruptive or not, it is still of Archæan origin; hence its relations with the later stratified series are only those of rigid underlying masses, and the local metamorphism observed in the limestones near the granites is strictly mechanical, and not to be mistaken for the caustic phenomena of a chemically energetic intrusion. It should be mentioned, however, that it possesses, both in its interior composition and in a peculiar conoidal structure, close affinities with the unmistakably eruptive granites of the Sierra Nevada; and it is quite possible that subsequent study will determine the presence here of two distinct granites, the one having a regular bedding and belonging to the stratified Archæan series, the other of conoidal structure and eruptive origin. The main body extends about twelve miles northeasterly, from the trachyte slopes of the Traverse Hills to the head of the Little Cottonwood Cañon. Its greatest north-and-south expansion is through Lone Peak, a line about eight miles long. South of the mouth of Cottonwood Cañon a narrow isolated patch of granite appears involved in the Archæan schists. . . . . Passing up Cottonwood Cañon, no sharp line of division between the structureless granite and the bedded gneissoid form is observable; but there appear gradually more and more planes having an easterly dip, until finally they approach the regularity of gneiss bed-planes, and the minerals are seen to possess a vague general parallel arrangement. . . . . The mineralogical differences through all these bodies of granite are indeed slight; changes of texture and arrangement produce a decidedly varying petrological effect, but in general they are granites, containing — besides the normal orthoclase, quartz, and biotite — plagioclase, hornblende, titanite, and apatite in high proportion; all but the apatite being visible to the naked eye. . . . . There are present in this neighborhood, then, two distinct families of rocks: first the Archæan, consisting of schists and granite; second, the vast, conformable post-Archæan group of sediments. Wherever observed, the region of contact between the two families displays no marked metamorphism on the part of the sedimentary series, and within the Archæan series no such transitions as would lead to the belief that the granite is only a more highly metamorphic form of the crystalline sedimentary series; on the contrary, the contact is so clearly defined, and the rocks are mineralogically so dissimilar, that it is very evident that the granite is either an intrusive mass or else an original boss over which the Archæan sedimentary materials were deposited. While the granite itself bears a very close resemblance to the Californian eruptive granites, its relation to the flexed Palæozoic strata would indicate that they were bent around a solid body, not that a plastic granite intruded into the bent Palæozoics. The absence of granite dikes penetrating the immense sedimentary series would strengthen the belief that the granite antedated it. It is also noticeable that the dip and strike of the Archæan schists west of the granite body are entirely discordant with the overlying Cambrian series, the former striking northeast and dipping northwest, the latter striking northwest and dipping southeast, this unconformability being preserved up to the contact. Supposing the whole Archæan body

to have been thrust upward and eastward when the flexure of the Palæozoic series took place, the present dip of the Archæan schists and quartzites would indicate that before the great Wahsatch uplift they were in a nearly vertical position, flanked to the east by the granite mass."

We may now investigate a little more in detail the question of the nature and origin of the granite, as well as the theories put forth by Messrs. King and Emmons, to account for the stratigraphical position of the rocks of the Wahsatch Range. In examining further we find that Mr. King divides the eruptive granites of his survey into four types (I., p. 107), and remarks : —

"This classification, based upon field observations, is interestingly carried out by Zirkel, whose microscopic examinations in every way confirm the field arrangement." (I., p. 109.)

Of these types the Wahsatch granite is taken as the youngest ; but he says : —

"There is absolutely no evidence whatever in favor of the belief of granitic extrusions later than the Archæan age. . . . . As an instance of how dangerous any attempt to correlate age by petrological features alone really is, may be cited the Jurassic granite of California and the granite of the Cottonwood region on the Wahsatch, which is unmistakably Archæan. They are positively identical down to the minutest microscopical peculiarity." (I., p. 111.)

We now turn to the work of Professor Zirkel, whose manuscript was revised by Mr. King and his assistants previous to its publication. And since all his information in regard to the field relations of the rocks was obtained from them, we may assume that his statements give a fair idea of Mr. King's views at the time of its publication. He remarks : —

"The decidedly eruptive granites may be divided into two classes : one embraces those older rocks that are of ante-Jurassic age ; the other, those which have obtruded themselves through the Jurassic strata. For the enormous mass of eruptive granite of the Sierra Nevada, Professor Whitney has demonstrated a Jurassic origin ; and, although not definitely proven, a similar age is assumed for a considerable class of granites along the Fortieth Parallel, whose petrographic constitution and habitus are identical with those of the Sierra Nevada. The full details of the reasons of this assignment will be found in the chapter upon granites in Vol. I. of this series. When, therefore, in this memoir, Jurassic granite is spoken of, the intention is to designate that family of which the Sierra Nevada occurrence is the type in age and constitution. . . . . Clarence King has long since shown that the eruptive Jurassic granites, and only these, are characterized by the presence of macroscopical titanite." (VI., pp. 39, 40.)

It has been seen that Mr. King divided the eruptive granites into

four groups, a classification which, as he states, Professor Zirkel's "microscopic examinations every way confirm"; but, in point of fact, the latter divides them into two classes, the older eruptive granites containing no titanite, and the younger eruptive or Jurassic granites which are characterized by the presence of that mineral. (VI., pp. 58, 59.) The Wahsatch granite is regarded as the most characteristic type of the younger or Jurassic granites bearing titanite. (VI., pp. 50–52.) We have been unable to find in the writings of Messrs. King, Emmons, and Hague any statement why their ideas of the age of these granites underwent so radical a change after 1876, — any reference to new evidence discovered, or to the views previously held, — or how, in the light of what Professor Zirkel says in the chapter upon granite, he can be quoted as then sustaining Mr. King's views as published in 1878.

If Mr. King's ideas regarding the origin of the supposed Archæan are correct, thus far he has not been able to show that the rocks with which the Archæan is in contact are older than the Quebec group. In fact, he and his assistants have failed to bring forward any proof of value in support of their position. Rocks found in contact with others show by their relations, as a general rule, whether they (1.) were deposited against them as a sea-shore cliff; (2.) have been pressed against and through them as a solid mass; (3.) were chemically deposited in contact; (4.) came as intrusions, overflows, or in any other way. Each occurrence has its own individual characters. These characters, in the study of cases like the preceding, should be known from the examination of rocks whose origin and relations are known. We fail to find any evidence in their publications that Mr. King and his assistants looked for that proof which, if their views are correct, should exist in overwhelming abundance.

Where sedimentary rocks of Potsdam age have been deposited in contact with the Azoic rocks of Lake Superior, they show by the enclosed fragments that they were derived from the latter; they show, on examination of the contacts, that the Potsdam was deposited against a water-worn cliff; no sign of mechanical, eruptive, or any other force, except the impact of water, is to be observed. Had there been other forces acting to any amount along the contacts their effects would have been visible, and their history could be made out to a greater or less extent. So in the case of the Wahsatch Mountains, if the Palæozoic rocks were deposited against such cliffs as Mr. King imagines to have existed, the evidence to prove this should have been sought for. Abundant *débris* from the cliffs ought to have been found in the Palæozoic

sediments. There cannot be a stratified deposit laid down upon a pre-existing surface, conforming to its irregularities in such a manner as to present itself in the form of continuous layers. Yet Mr. Emmons describes such a phenomenon: hence the only conclusion following his views is that the solid granite slid up along the bottom of the quartzite, bending it so as to cause it to conform with the irregularities of the granite, and this elevation of the solid granite must have metamorphosed the limestone, and corrugated and uptilted all the adjacent formations: yet with all this the gentlemen studying the locality fail to show any evidence that the granite was solid at the time. Is it possible that an enormous mass of rough jagged granite could have been pushed like a huge rasp in contact with quartzites, limestones, etc., and have left no trace of its movement upon them? So, too, if it were intrusive, it should in like manner show by its contacts that such was the case. Instead of raising so extraordinary a fabric of theory on so slender a basis of facts, it would have been better to study the region a little more thoroughly. To us it appears highly probable that the granite was of eruptive origin, and of later than Archæan age. It is certain that the section of the Wahsatch Range given in the Atlas of the Fortieth Parallel Survey does not conform to the theories of Messrs. King and Emmons; and, moreover, that it represents impossible stratigraphical conditions.

Views very similar to those here expressed by the writers of this paper have already been published by Professor Geikie, Director of the Geological Survey of Great Britain, in an article having as its title, "On the Archæan Rocks of the Wahsatch Range" (Am. Jour. Sci., 1880, (3) XIX., pp. 363–367). From this paper the following extract is made, and it will be a sufficient indication of the light in which Mr. Geikie regards the geological speculations of Messrs. King and Emmons touching the structure and age of the range in question.

"According to the Reports of the Exploration of the 40th Parallel, the Wahsatch Mountains consist of a central core of Archæan rocks, composed partly of granites and partly of various quartzite, schists, and other crystalline masses. These rocks are represented as having formed an island in the Paleozoic sea: and Mr. King asserts that the island must have presented to the west an almost precipitous face of 30,000 feet, or upwards of 5½ miles — an altitude exceeding that of any mountain chain. Round this lofty Archæan island the whole of the Paleozoic and Mesozoic sediments are said to have been deposited to a depth of from 30,000 to 40,000 feet, in one continuous uninterrupted series. Subsequent terrestrial movements, acting along the line of the original island, have upraised the surrounding sedimentary masses, and the ancient

crystalline rocks have once more been revealed by denudation. Now the fact of the existence of a cliff more than 5½ miles high would require to be established by very carefully collected and convincing evidence. It was with very considerable curiosity, therefore, that I paid a visit to the Cottonwood district, where the evidence was said to be most complete. I must frankly own that I failed to observe any grounds on which the assertion appeared to me to be warranted. One would naturally expect that if a mass of strata 30,000 feet thick had been laid down against a steep slope of land, its component beds ought to be full of fragments of that land. Each marginal belt, representing an old shore-line, should be more or less conglomeritic; at least, there ought to be occasional zones of conglomerate, just as at the present day, we have local gravel beaches on our shores. But I could find no trace of pebbles. It would of course be presumptuous in me to assert that they do not exist; but they are not mentioned by Mr. King, nor by Messrs. Hague and Emmons, and yet, as their evidence would be so important, we can hardly suppose that these writers observed them and made no reference to the fact. But not only have no pebbles of the Cottonwood granite been recorded as occurring in the overlying Paleozoic rocks, it is admitted that these rocks become metamorphosed as they approach the granite. The natural inference to be drawn from these facts, one might suppose, would be that the granite is later in date than the rocks overlying it. Mr. King admits that the granite has been undoubtedly the centre of local metamorphism, but this change he regards as 'strictly mechanical and not to be mistaken for the caustic phenomena of chemically energetic intrusion.' How he would discriminate between a mechanical and chemical cause producing precisely the same ultimate effect he does not explain. . . . .

"But if I am correct in regarding the Wahsatch granite as of post-Carboniferous date, then we are relieved from the uncomfortable incubus of these primeval mountains. We are not required to believe in the existence of a cliff 5½ miles high, which maintained its position and steepness during the greater part of all geological time. And we are spared the necessity of a colossal fracture of 30,000 feet on the west side of the Wahsatch Mountains."

We see no reason for proceeding further in the examination of the work of the Fortieth Parallel Survey. Enough has been said to give a sufficient idea of its character and value, as bearing on the question before us. In brief, the whole matter may be thus summed up: —

All the crystalline and the eruptive rocks, between the Wahsatch and the borders of California, with the exception of the modern volcanic ones, have been called by the geologists of this survey "Archæan." In not a single instance, so far as we are able to make out, has there been positive proof given that the rocks thus assigned were really of that age. In many cases the stratigraphical conditions are of a kind that such proof could not possibly have been obtained. In order to maintain the view of the Archæan age of the rocks in question in certain

regions, the most extraordinary, and as it seems to us impossible, dynamic conditions have been invented, and sections drawn which are not consistent with the theories advanced, nor with the observations of Professor Geikie, nor with those of the senior author of the present paper. An attempt has been made to divide the granite into eruptive and metamorphic; and it is claimed that the division thus made in the field was supported by the independent microscopical examination of Professor Zirkel. In point of fact, however, it appears that the latter only observed certain differences between two sets of rocks submitted to him by the geologists of the Fortieth Parallel as having been determined, in the field, to be eruptive and metamorphic. These differences, however, are considered by Dr. Wadsworth to be non-essential, and not such as would, in the case of other specimens from other regions, justify the lithologist in assigning rocks so differentiated to different origins. Indeed, Professor Zirkel, as already stated,* admits this. Furthermore, it appears that at the close of the field-work the crystalline and granitic rocks of the ranges of the Great Basin west of the Wahsatch were considered by Mr. King as being of post-Jurassic age, in accordance with the observations and results of Professor Whitney and his assistants on the Geological Survey of California; but that some years later, at the time of the publication of the volume of Systematic Geology, these rocks were all classed as Archæan, without any reference to the fact that so radical a change of views on a point of so much importance had taken place, and with no sufficient evidence for its support. It needs hardly be added, that any reference to a division of the Archæan (Azoic) into sub-groups in the Fortieth Parallel reports can only be looked upon as wholly without importance or value, otherwise than as indicating certain mineralogical resemblances to rocks described as occurring in Canada and elsewhere.

HAYDEN'S SURVEY.

In 1868 Dr. F. V. Hayden remarked that the "metamorphic rocks" in the valley of the Chugwater (Wyoming) were probably of Laurentian age, but it is not stated upon what evidence this opinion was founded. (Report of Commissioner of the General Land Office, 1868, p. 232;

* See *ante*, p. 500.

U. S. Geological Survey of the Territories, 1867, 1868, and 1869, [1873,] p. 79.)

In the Report of the U. S. Geological Survey of Colorado and New Mexico, 1869, (pp. 22, 73, 87,) and in the publication last mentioned above (pp. 122, 173, 187), Dr. Hayden presents a clear statement of his views regarding the supposed Laurentian rocks in the region examined by him. He gives, however, no evidence in support of these views. It is simply a profession of faith, in the following words: —

"I have assumed the position that all the rocks of the West are, or were, stratified, and that where no lines of stratification can be seen, as in some of the massive granites, they have been obliterated by heat during their metamorphism. . . . . This iron occurs in the gneissoid rocks, or what is called the Laurentian group, to which group, I believe, all the gneissic and perhaps the entire mass of metamorphic rocks of the Rocky Mountain system belong. I have assumed the position, in all my investigations, that there are but two classes of changed rocks in the West, viz., igneous and metamorphic, and that the oldest granites which form the nuclei of the loftiest mountain ranges were once aqueous rocks, deposited in the same manner as the limestones or sandstones of our most modern formations. . . . . The gold and silver lodes of this Territory [Colorado], so far as they are observed, are entirely composed of the gneissic and granite rocks, possibly rocks of the age of the Laurentian series of Canada."

On the same page from which the last remark is copied, Dr. Hayden distinctly shows that he regards the foliation of gneissoid rocks as synonymous with bedding and stratification. Had all our geologists been as frank regarding the theoretical views upon which their work is based, it would be far easier to estimate the value of their observations.

In the Annual Report for 1870 the same view of the age of the rocks in the valley of the Chugwater was repeated. Of the rocks on the north side of the Uinta Range, near the head-waters of Bear River, Dr. Hayden remarks: —

"In all this series of strata, from the red beds to the oldest quartzites, I was able to detect no unconformability. . . . . I am inclined to believe that the upper beds are Silurian, that they pass gradually down without any break in the sequence of time to rocks of Huronian age. The purplish quartzites are almost precisely like those which occur at the Sioux Falls in Dakota, and at the Pipestone quarry, in color and texture, which Professor Hall regards as Huronian age." (*l. c.*, pp. 14, 50.)

The above quartzite appears to be the Weber quartzite (Carboniferous) of the Fortieth Parallel Survey, and the Uinta sandstone (Devonian) of Major Powell (Systematic Geology, p. 152; Geology of the

Uinta Mountains, p. 70). Hence, as it appears, considerable difference of opinion exists as to its age. Mr. S. F. Emmons apparently inclined to regard it as Cambrian (Descriptive Geology, p. 199), while Professor Marsh and Dr. C. A. White thought it probable that it was Silurian (Am. Jour. Sci., 1871, (3) I., p. 193 ; Annual Report, 1876, p. 23). In his Annual Report for 1871, (p. 39,) Dr. Hayden remarked : —

"The precious metals, as gold and silver, are found, so far as my observations have extended, entirely in the metamorphic rocks which hold a position below all groups of strata that we have been in the habit of regarding as Paleozoic. Whether they belong to the series denominated in Canada the Huronian or Laurentian, we have no data to decide positively ; but inasmuch as they are all clearly stratified rocks, they are plainly of sedimentary origin."

In the Report for 1873, Dr. Hayden stated that

"the underlying metamorphic rocks [near South Park] are made up in part of quartzitic sandstones, full of rounded pebbles of quartz, which would indicate that they might belong to the Laurentian series." (*l. c.*, p. 41.)

In the Report for 1874, (pp. 190, 191, 239,) Dr. F. M. Endlich held that the granite and other so-called metamorphic rocks were formed from the metamorphosis of the Silurian and Devonian rocks in the district studied by him.* These rocks appear to be the same as those called Archæan by the other members of the Survey. (See also Report for 1875, p. 113.)

In the Annual Report for 1875, Dr. A. C. Peale makes the following statement : —

"Sufficient data have not yet been obtained to determine the exact age of the metamorphic series, although, as Marvine remarks of those farther east, [Annual Report, 1873, p. 139.] 'the prevalence of siliceous and granitic types recalls the descriptions of Laurentian areas.' In one place the schists are very distinctly stratified, consisting of dark micaceous schists, with seams of quartz and feldspar. These may be of Huronian age, although we cannot trace their relations to those of the other Archæan rocks, as they are exposed in an isolated area at the bottom of cañons distant from the other outcrops." (*l. c.*, p. 64.)

In the Annual Report for 1877, (p. 156,) Dr. F. M. Endlich, in a tabular view of the formations of the Sweetwater district, divides the Azoic rocks into three systems. The oldest of these, called Prozoic, consists of massive granite. The third, called Huronian, likewise consists of granites, less massive than those of the first system, and con-

* The area between the meridians of 107° and 108°, and the parallels of 37° 15′ and 38° 15′, at the head of the Rio Grande and the Rio Animas.

taining darker-colored micas. The intermediate system, to which the name of Laurentian is given, is said to be made up of schists "composed of quartz, feldspar, hornblende, and mica." This classification seems to be purely a mineralogical one, and not justified at all — in so far, at least, as the giving of the names Huronian and Laurentian is concerned — by anything observed in the field. Indeed, Dr. Endlich himself states that,

"although special examinations were made to determine whether the different mineralogical constitution of the [metamorphic or Archæan] rocks remained constant within certain zones, no applicable data upon this point could be obtained. . . . . Within the main chain the stratoid segregation of the granites is not very completely carried out. . . . . It would require the most careful examinations, conducted on a liberal scale, as to time, to elicit evidence bearing upon the former condition of this metamorphic area." (*l. c.*, p. 66.)

Much the same may be said, with truth, of the division of the Azoic series into sub-systems by Dr. Hayden's assistants, Professor St. John and Dr. A. C. Peale. The former assigns the crystalline rocks of the Teton district to the Laurentian and Huronian systems, placing the granites and gneisses in one division, and the quartzites and slates in the other, there being no stratigraphical basis whatever indicated for this arrangement. The reference to the Huronian is, indeed, suggested only with doubt by Professor St. John. (*l. c.*, p. 480.) The same is true of the division of the Archæan into "Huronian?" and "granite," given by Dr. Peale. (*l. c.*, p. 612.)

It appears on examining the published volumes of the Hayden Survey, as well as from personal investigation of a part of Central Colorado by one of the authors of the present paper, that through the whole extent of the Cordilleras, and especially in the Rocky Mountain region proper, the axes of the mountain chains are usually made up of crystalline rocks, entirely destitute of fossils. These rocks are chiefly granites and gneissoid granites; slates occur in extremely subordinate quantity. In the northern portion of the chain, where the entire Palæozoic series, including the Potsdam sandstone, is developed, there could be no hesitation in assigning these *when not eruptive* to the Azoic or Archæan. But it is not certain that there is any Archæan proper in the whole range of the Cordilleras; and in most cases it is beyond doubt true that the axes of the chains have been erupted and the stratified masses uplifted at a period much later than the Azoic. Thus, for instance, we have in California post-Jurassic and post-Miocene eruptive granitic centres or axes, in the Sierra Nevada and Coast Ranges respectively.

Furthermore, in the Central and Southern Rocky Mountains we find that a large portion of the lower divisions of the series of stratified rocks is wanting. Thus in the Front Range of Colorado the crystalline masses are directly overlain by rocks generally admitted to be of Triassic age. In such cases, and in these regions, we have the same difficulties which occur in the Appalachian ranges; it is — or at least has been up to the present time — very difficult for most geologists to clearly distinguish, either in the field or in the cabinet, between metamorphic eruptive and metamorphic sedimentary rocks.

WHEELER'S SURVEY.

In the Reports of the Geographical and Geological Survey west of the one hundredth Meridian, under Capt. Geo. M. Wheeler, we have seen no evidence advanced to prove the occurrence in the supposed Azoic areas examined by that Survey of distinct geological formations.

Of the rocks called "Archæan" in the region explored in 1878 and 1879, embracing portions of North Central New Mexico and South Central Colorado, Professor Stevenson says: —

"No absolute evidence exists to settle the age of these rocks. Lithologically they bear close resemblance to the Laurentian series of the east, and at more northern exposures within the Rocky Mountain region they have been referred by all observers to that age. The coarse gneissoid and often conglomerate granite immediately underlying the Carboniferous at many localities may possibly be of somewhat later origin." (Wheeler's Report, Vol. III., Supplement, p. 72.)

JONES'S SURVEY.

In a Report upon the Reconnoissance of Northwestern Wyoming by Capt. Wm. A. Jones, in 1873, Prof. Theo. B. Comstock remarked on the Azoic rocks examined by him: —

"There are some slight reasons for placing a portion of the oldest of these rocks in a group nearly equivalent to the Laurentian system of the East, but it must be confessed that none of them are based upon much better foundation

than a certain similarity to that formation in lithological characteristics. Their position upon the stratigraphic chart is, therefore, entirely provisional." (*l. c.*, p. 106.)

POWELL'S SURVEY.

In the publications of the U. S. Geographical and Geological Survey, under Major J. W. Powell, we are able to find but little relating to the subdivision of the supposed Azoic rocks examined by that Survey.

In a "Report on the Geology and Resources of the Black Hills of Dakota," by Henry Newton and Walter P. Jenney, published in connection with Major Powell's Survey, and revised by Mr. G. K. Gilbert, the granite is shown to be eruptive along the foliation of the schist, and not a sedimentary rock. An attempt is made to divide the rocks of the region into two ages, Laurentian and Huronian; but they do not appear lithologically to have the characters of either formation. The division into two groups is stated to be a lithological one only, as the two series conform in strike. A diversity of dip is said to have been observed at one point, but that observation is not insisted upon.

Furthermore, however, we find it stated that "the lithological evidence fails to give even its feeble support to the theory that the two Archæan groups of the Black Hills are the representatives of the two Archæan groups of Canada." (*l. c.*, pp. 45–80.)

CALIFORNIA.

The geological investigations of the California Survey, carried on from 1860 to 1874, show that the gold-bearing slates of the Sierra Nevada are of Jurassic and Triassic age. No fossils older than the Carboniferous have ever been found in that range. The Mesozoic series has been uplifted by eruptive granite, which forms the axis of the chain. On these uplifted rocks strata of the Cretaceous epoch rest unconformably and almost without disturbance. Hence it is a well-established fact — the geological age of the different formations having been made out by the discovery of fossils at numerous localities, and reference to their

proper position by skilful palæontologists — that the upheaval of the Sierra Nevada took place between the Jurassic and Cretaceous epochs.

In like manner, the age of the strata making up the Coast Ranges of California has been shown, by discovery of fossils in numerous localities, to be Cretaceous and Tertiary. These strata have been uplifted at various times during the Tertiary epoch, in some regions even as late as the post-Pliocene.*

Of course, such being the case, there can be no rocks in California which can be properly said to belong to the Azoic system (Archæan).

In view of these facts, for the purpose of throwing further light on the methods and theories of Dr. Hunt, as set forth to some extent in the preceding pages, it will be well to quote some of the remarks published by him at various times in regard to the rocks of California.

In 1866 Dr. Hunt stated : —

"The notion that gold belongs only to rocks of Lower Silurian age, was many years since disproved by its discovery in the Upper Silurian slates of eastern Canada, and more recently, it has been shown that the great gold mines of California are in strata far more recent, and chiefly of the Jurassic and Triassic periods." (Geol. of Canada, 1866, p. 196.)

In 1868 Dr. Hunt again states : —

"The auriferous rocks of California belong to the Mesozoic period, being of Jurassic age." (Gold Region of Nova Scotia, 1868, p. 11.)

In 1877, however, Dr. Hunt visited California for the first time, and, having spent several days in the Sierra Nevada, published the following statement (Am. Assoc. Adv. Sci., 1877, XXVI., p. 266 ; Proc. Bost. Soc. Nat. Hist., 1878, XIX., pp. 276, 277 ; Macfarlane's "Geologist's Travelling Hand-Book," p. 13 ; Azoic Rocks, p. 244) : —

"Eruptive granites are found in California, where they abound among the foot-hills of the Sierras, in Placer and Nevada counties. The crystalline schists observed by the speaker in these counties, and in Amador county, are Huronian, and have all the characters of the Huronian series as seen in the eastern regions of North America, and of the *pietri verdi* of the Alps. To this horizon are also to be referred the similar crystalline rocks of the Coast range of California, as seen near San Francisco and San Jose. The auriferous veins which, in the Rocky Mountains, intersect the Laurentian gneisses, are found

* See Geology of California, Vol. I. *passim ;* and, for full information in regard to the geological age of the rocks of the gold-bearing belt, "The Auriferous Gravels of the Sierra Nevada of California," Contributions to American Geology, Vol. I. pp. 34–39.

in the Sierras alike in the Huronian schists and in the eruptive granites, which probably penetrate the Huronian series."

Dr. Hunt stated that the crystalline schists of the Sierra Nevada examined by him have "all the characters of the Huronian series as seen on the great lakes." (Proc. Bost. Soc. Nat. Hist., 1878, XIX., p. 276.)

In 1880 Dr. Hunt further stated that the gravel at the Blue Tent placer mine, in Nevada County, California, is "made up in great part of the débris of the crystalline Huronian schists of the region, including much greenstone or diorite rock." (Trans. Am. Inst. Min. Eng., 1880, VIII., p. 452.)

The present writers, having had occasion to make a prolonged and most careful examination of the rocks of the Sierra Nevada, and of the Coast Ranges of California, as well as of those of the south shore of Lake Superior, take occasion to remark, that no such resemblances as those pointed out by Dr. Hunt have any real existence. The rocks of the California Coast Ranges, even where most metamorphosed, differ, both microscopically and macroscopically, from those of the Sierra Nevada, and specimens from the two regions in question would never be mistaken for each other by any one having even a moderately well trained eye. In the same way, the slaty crystalline rocks of the Sierra Nevada differ nearly as much from those of the Azoic regions of Lakes Huron and Superior as do the basaltic lava-flows of the latter region from those of Mount Ætna. Macroscopically, the rocks of the two series could never be confounded with each other, and microscopically the differences are equally striking. Hence it appears that, while the palæontological evidence is entirely averse to the dicta of Dr. Hunt in reference to the Huronian age of the Coast Range and Sierra Nevada rocks, even the lithological characters are quite as little in harmony with his views. Recalling what Professor Dana has remarked in reference to the Lower Silurian age of Dr. Hunt's Vermont Huronian, it may here be added, that the latter has, by what he has published in regard to California, made out the Huronian to be also Mesozoic and Tertiary, so that this formation may be said now to represent, according to Dr. Hunt's views, the whole geological column from top to bottom.

PART II.

Résumé, and General Discussion.

The great length of the preceding division of this contribution to our knowledge of the older geological formations of the United States and the adjacent northern region makes it necessary for us to offer, in this second and concluding portion of our work, but a brief synopsis of the conclusions at which we have arrived in the study of these older rocks. We have already set forth, in considerable detail, the theories which American geologists have held at various times in regard to those older crystalline rocks to which the names Archæan and Azoic have been commonly applied, and in doing this we have had special reference to the necessity or possibility of dividing that series of rocks into two or more distinct groups. We have given the evidence on which these various theories were based with considerable detail, because the facts which developed themselves, as we pursued our inquiry, were so extraordinary that we felt it to be doubtful whether our statements would be accepted as truthful unless we presented the reader with the means of verifying them at once, on the spot, without the necessity of examining a long series of volumes, some of which are only to be obtained with the greatest difficulty. More work has, however, been done by us, both in the field and in the laboratory, in the investigation of the subject here discussed, than the cursory reader of the present article would perhaps be inclined to suppose; and we trust that the opportunity may yet be furnished us for carrying this work still farther in the same direction, and for presenting the whole body of the results which we have reached, as well as those which may hereafter be attained, in a fuller form than it is possible for us to do at the present time.

We think that it is impossible for any unprejudiced worker in this department of science to peruse with care the preceding pages, and not feel obliged to admit that the geology of a large portion of this country, and especially that of Canada and New England, is in an almost hopeless state of confusion. We think that it must have been made clear to the candid mind, that the geologist would find himself completely baffled who should endeavor to obtain any definite knowledge of the real

nature and order of succession of the rocks which cover so large a portion of the region in question from the study of that which has been published with regard to them. We believe that we are justified in going still farther, and saying that our chances of our having at some future time a clear understanding of the geological structure of North-eastern North America would be decidedly improved if all that has been written about it were at once struck out of existence. That this condition of things is largely due to the erroneous observations and theories of the Canada Survey, which to a large extent have been adopted and blindly followed on this side of the Dominion boundary, is a statement the truth of which we think no one who has carefully studied the evidence presented in the preceding pages will not feel obliged to admit. While not desiring to conceal the fact that some of the problems presented in the course of the study of the older rocks are extremely difficult, we find it clearly proved that want of knowledge, want of experience, and a desire to produce sensational theories, have brought about this condition of confusion. Some of the salient points which have presented themselves in the course of this investigation into the history of geological opinion in this country will therefore now be passed in review, and the subject then left, for the present, to the reader's candid consideration.

The establishment of the Silurian System by Murchison opened the way to the discussion of the question whether the lowest limit of life in the geological series had been, or was likely to be reached. The fact that in England the lower fossiliferous rocks are greatly disturbed and metamorphosed, and that consequently their order of succession is very difficult to make out, rendered it much less easy to arrive at any definite conclusions in regard to this question than it was in countries like Bohemia and the United States, where the Silurian strata, over large areas, rest in undisturbed succession upon each other. Before, however, the investigations of Barrande had led him to infer that there was a distinct limit to traces of life in the descending order of formations, Murchison had arrived at this result, led thereto by his geological work in Scandinavia, which country he had visited in connection with his reconnaissance of European Russia, and where a large amount of detailed investigation of the lower rocks had already been made by the able Swedish geologists, all of which was placed at his disposition.

The first use of the term "Azoic," with an approach to a definite meaning, was made by Murchison, with reference to the rocks of Scandinavia. His statement was as follows: —

"On this point we have recently convinced ourselves, by clear and indisputable sections, that the lowest beds charged with anything like animals or vegetables are the exact equivalents of the Lower Silurian strata of the British Isles, and that these have been distinctly formed out of, and rest upon, slaty and other rocks which had undergone crystallization before their particles were ground up and cemented together to compose the earliest beds in which organic life is traceable. To the crystalline masses which preceded that palæozoic succession to which our researches were mostly directed, we apply the term 'Azoic,' not meaning thereby dogmatically to affirm, that nothing organic could have been in existence during those earliest deposits of sedimentary matter, but simply as expressing the fact, that in as far as human researches have reached, no vestiges of living things have been found in them, so also from their nature they seem to have been formed under such accompanying conditions of intense heat and fusion, that it is hopeless to expect to find in them traces of organization. . . . . In the term Azoic rocks, we include all the crystalline masses belonging to the ancient group of gneiss, together with ancient granitic and plutonic rocks by which they have been invaded."*

It will be noticed that Murchison considered that his "Azoic" rocks — in Scandinavia, at least — seemed to have originated under such conditions that the existence of organic life at the time of their formation was impossible; yet, as he hastens to add, he was not willing "dogmatically to affirm" that these rocks might not contain fossils. It is not easy to understand exactly what Murchison meant by these two evidently contradictory statements; but this want of tenacity of opinion in regard to the truly azoic character of the infra-Silurian rocks was still further exemplified in the various editions of his "Siluria," in the course of which we see the author passing gradually from an upholding of a series of necessarily non-fossiliferous "bottom rocks," up to a positive recognition of the Laurentian and Huronian systems of the Canada Survey, and the admission that the rocks designated as "Azoic" and said to be *necessarily azoic*, did furnish proofs of the existence of life on the globe at the time of their formation.†

* Proc. Geol. Soc. London, Vol. IV. (1845), p. 602. The Geology of Russia in Europe, and the Ural Mountains, Vol. I. (1845), p. 10.

† In the first edition of "Siluria" (1854), the rocks called in "Russia and the Ural Mountains" Azoic are designated by the term "Bottom Rocks," and they are said to "lie below all those formations in which there are *the slightest vestiges of Silurian life*." These rocks are also said to have been "formed, as I [Murchison] believe, at a period when the heat of the earth was antagonistic to the existence of living beings." In the third edition of the same work — the second is not at hand for reference — the Azoic rocks are designated as "primeval" and "fundamental," and it is said that "they *may* have been formed at a period when the heat of the earth was antagonistic to the existence of living beings." In the fourth edition of

Barrande, in his earliest communication embodying the results of his life-work among the Palæozoic rocks of Bohemia (1846), did not use the term "primordial," which he later adopted, and in which he included the lowest zone of life; but he speaks of his division "C" as "forming the base of the Protozoic rocks, according to the latest classification of the Rev. Professor Sedgwick." His (Barrande's) groups "A" and "B" constitute the "Lower Division," comprising all the Azoic formations, subdivided into two groups, their upper one ("B") being identified by him as the equivalent of Sedgwick's Cambrian, — the confusion in geological nomenclature caused by the introduction of this term having begun as far back as these earliest days of discussion in regard to the Azoic and Palæozoic rocks.

It appears, however, that Sedgwick, as late as 1854, had not arrived at any definite conclusions in regard to the existence of an Azoic series, for he says of his Cambrian, "that it seems to contain no organic remains." But he hastens to add, that the answer to the question when organic life began "is involved in inextricable obscurity." *

In 1851† Messrs. Foster and Whitney made known the existence of a series of rocks on the south shore of Lake Superior, in regard to which they wrote as follows: —

"Below all the fossiliferous groups of this [the Lake Superior] region, there is a class of rocks, consisting of various crystalline schists, beds of quartz, and saccharoidal marble, more or less metamorphosed, which we denominate the Azoic System. This term was first applied by Murchison and De Verneuil to designate those crystalline masses which preceded the Palæozoic strata. In it they include not only gneiss, but the granitic and plutonic rocks by which it has been invaded. We adopt the term, but limit its signification to those rocks which were detrital in their origin, and which were supposed to have been formed before the dawn of organized existence." ‡

It is now known that a large part of the vast region adjacent to Lake Superior on the north and east, and included within the limits of Canada and British North America in general, is occupied by rocks which by their infra-Silurian position and lithological character belong in the

"Siluria" (1867), the Azoic is called "Laurentian," and is regarded as being "the base of all Palæozoic deposits."

* British Palæozoic Rocks and Fossils, 1854, Introduction, p. xxxii.

† A synopsis of their results had in the previous year (1850) been presented to the Department of the Interior, and in this the nature and geological position of the "Azoic System" had been clearly set forth. Senate Documents, 2d Sess. 31st Cong., 1850–51, II., Doc. 2, pp. 147–152.

‡ Foster and Whitney's Report on the Geology of the Lake Superior Land District, Vol. II. The Iron Region, together with the General Geology, 1851, p. 3.

Azoic of Foster and Whitney. These rocks had been met with by the geologists of the Canada Geological Survey, and were designated by them in the Report of Progress for 1845–46 as the "Metamorphic Series,"* their geological position not having been clearly ascertained, nor the question considered whether the lowest Lower Silurian really formed the base of the fossiliferous strata, so that rocks underlying them unconformably could properly be called Azoic.

After the publication of Foster and Whitney's Report — in 1854, namely — Mr. Logan, the chief of the Canada Survey, recognizing the fact that the term "metamorphic" had no special significance as designating the geological age of any group, since rocks in any part of the series may be metamorphic, adopted for the Azoic of Foster and Whitney the designation of "Laurentian," a name previously proposed by an eminent authority for a group at the other end of the geological series, and already in current use — an act of great injustice, as we have already pointed out.† Neither was any reference made in the report of the Canada Survey, in which the name "metamorphic" was exchanged for that of "Laurentian," to the fact that the geological position of these rocks had previously been definitely established, and another name given to them by the American geologists working on the southern side of Lake Superior.

Furthermore, owing to the inability of Mr. Logan to distinguish between the Azoic quartzites of Lake Huron, and the very dissimilar sandstones, conglomerates, and interbedded volcanic rocks of Keweenaw Point, utter confusion was introduced into the geology of the region of the Upper Great Lakes — in the minds, at least, of those accepting the dicta of the Canada Survey as authority — a condition of things which was not fully rectified until many years later.‡

For some time after the introduction of the term "Azoic" into the geological nomenclature by Foster and Whitney, that term was current among geologists in this country. Dana, in the first edition of his "Manual of Geology," the Preface of which bears the date of November 1, 1862, and in the revised edition, issued in 1871, in which it is stated that the work "has received such alterations as seemed to be

* See *ante*, pp. 331 *et seq.*

† See *ante*, pp. 7, 338. Also, Am. Jour. Sci., (2), XXIII. 305–314; Proc. Bost. Soc. Nat. Hist., XXI. 121, 122.

‡ See a statement in reference to the results attained by the Geological Survey of Canada, published by A. R. C. Selwyn, present chief of that Survey, in "Science," number of February 9, 1883.

required by the results of recent geological research," adopts the term "Azoic," but not in the exact sense in which it was used by Foster and Whitney. He includes under that designation all the rocks which were in existence at the time animal life began, stating his views in the following words: "The Azoic rocks constitute the only universal formation. They cover the whole globe, and were the floor of the oceans and the rocks of all emerged land when animal life was first created. . . . . Whatever events occurred upon the globe from the era of the elevated temperature necessary to fusion, down to the time when the climate and waters had become fitted for animal life, are events in the *Azoic* age."

But farther on (*l. c.*, p. 145), Dana advocates the idea that there may have been life on the globe during the Azoic period, for he says, "The term 'Azoic,' as here used, implies absence of life, but not necessarily of the lowest grades." He then gives the following "reasons in favor of the existence of life of some kind [in the Azoic]." 1st. The formation of limestone strata. 2d. The occurrence of graphite in the limestone and other strata. 3d. The occurrence of anthracite in small pieces in the iron-bearing rocks of Arendal, Norway, which rocks are probably Azoic in age. He then proceeds to give reasons why, supposing the existence of life of some kind, it is more likely to have been vegetable than animal. But he distinctly admits (*l. c.*, p. 147) that "whenever the earliest plant, however minute, was created, then the grand idea of life first had expression, and a new line of progress in the earth's history was announced." And, still farther on (*l. c.*, p. 178), he admits that "*the life of the Potsdam period is the beginning of the system of life deciphered in American geological history.*"

In the second edition of his Manual, the Preface of which bears date March 1, 1874, Dana takes a position in reference to the Azoic system materially different from that previously occupied by him. He now introduces the term "Archæan," and defines "Archæan Time" as "the beginning, including a very long era without life, and finally that in which appeared the earliest and simplest forms of plants and animals." Farther on, however, (*l. c.*, p. 146,) he says, that "Archæan time includes strictly, as its commencement, an *Azoic* age, or the era in which the physical conditions were incompatible with the existence of life. *But this era, so far as now known, is without recognizable records;* for no rocks have yet been shown to be earlier in date than those which are now supposed to have been formed since the first life began to exist."

In view of the contradictions and confusion of ideas thus shown to prevail among the most eminent geologists in reference to the nomenclature of the oldest crystalline rocks, no one can do otherwise than admit that it is quite time that some more definite understanding should be had of this whole subject, and, as a contribution toward this desirable end the following remarks are submitted.

There are two essentially different ways of looking at the rocks which make up that portion of the earth which is accessible to investigation. One of these has reference to the manner in which these rocks have been formed; the other, to the chronological order in which they have come to occupy the position which they now hold. Roughly speaking, it is this idea which forms the basis of a division of the science of geology into two quite distinct departments, Dynamical and Historical Geology. For the study of the former a knowledge of lithology and petrology is indispensable, while the latter is chiefly an application of the results of palæontological investigation to questions of synchronism and order of succession in the rocky strata.

In considering other worlds than our own, no more important question could be asked in regard to them than this: Are they inhabited, or does organic life exist upon them? The only reason why this question is not oftener asked or more discussed is, that it is one to which a definite answer cannot now be given, while there seems to be extremely little chance that there will ever be any change in this respect. It is not beyond the bounds of possibility that some meteoric fragment may be dropped upon this earth bearing evidences of the existence of life on another world; but, up to the present time, the aspect of such bodies as have come to us from outside our own atmosphere has not been of a character to encourage any expectation that such an event may occur in the future. Still, it will hardly be denied by any one that proof of the existence of life on any of the planets, or any other of the heavenly bodies, would be accounted one of the most interesting revelations ever made to the human race. Similarly, to fix in the order of events through which this earth has passed the epoch when life began to exist on the globe, must be admitted to be a problem of high importance; and, as intimately connected with this, and of similar interest, would necessarily be the inquiry whether any rocks could be pointed out in regard to which it could be affirmed with truth that they were deposited, or brought into their present position, before the appearance of life on the earth.

Here, however, a point suggests itself as of importance in connection

with the present inquiry; namely, that while there may be rocks which are azoic because no life existed when they were formed, there are others which from the very nature of their mode of formation and occurrence could not show any indication of the presence of life, even although it may have existed on the same planet, and in the immediate vicinity of the rocks in question at the time they were deposited or placed in their present position. Thus, no one would expect to find signs of life in lava, or in the granitic masses originally constituting a part of the earth's crust, and which were formed at a time when the temperature and other conditions could not have been favorable to the development of life, but which may have been raised since their formation into perhaps close proximity to strata replete with the remains of organized beings.

On looking over the subject of the existence of "Azoic" rocks — that is, of such formations as are destitute of evidences of the presence of life at the time of their formation or deposition — we find that there are several categories in which such rocks may be classed.

1st. We may have strata, once fossiliferous, in which the evidences of life have disappeared in consequence of the metamorphic changes which those rocks have undergone. Experience shows that such cases are not uncommon; but that, usually, the geological age of such metamorphic strata may be recognized, either by means of their position with reference to strata of known age, or by tracing the metamorphosed formation to such a distance from the source of the alteration in question that we find the formation manifesting itself in its original condition. To such metamorphic strata we should never have occasion to apply the term "Azoic," since we should clearly recognize the fact that their azoic character was something which did not originally belong to them.

2d. Rocks may be azoic, even if laid down when life was existing on the globe, provided the local conditions were not favorable to its development at the particular locality under consideration. Thus, much the larger portion of the Potsdam Sandstone of Lake Superior is entirely destitute of traces of life; yet, as there are occasionally — even if very rarely — localities where this rock is fossiliferous, we should not think of separating the fossiliferous portions from the non-fossiliferous, or of calling them by any special name, in consequence of the absence of traces of life in them.

3d. Again, rocks must necessarily be azoic, when formed or originating under such conditions as were incompatible with the existence of life.

The original crust of the earth must have been azoic, if we adopt the views held by the large majority of geologists, that our globe has cooled from a former condition of igneous fluidity. The volcanic and eruptive rocks must necessarily be azoic, because they have come from the heated interior of the globe, reaching the surface, for the most part, in a melted condition. We do not, however, designate the eruptive and volcanic rocks as "Azoic"; the fact that they are necessarily in this condition is assumed as something self-evident.

4th. We may have rocks formed under such conditions as were not inimical to life, but yet azoic, because life had not begun to exist on the globe at the time of their deposition. These, according to our view, would be the rocks properly designated by the term "Azoic," and the body of rocks having this character might properly be called the "Azoic System." And we think that, in view of what has here been set forth, no one will deny that it is important that, if there are such rocks, they should have a special designation, and that the term "Azoic" would be a proper one to apply to them.

This, however, is exactly what was done by Foster and Whitney, in 1850, when they gave the name of the "Azoic System" to a body of strata, originally — in part, at least — of sedimentary origin, which did not show by their character that life could not have existed at the time of their deposition, but which proved, on examination, to be entirely destitute of fossils, and which, moreover, were found everywhere to underlie unconformably other stratified formations which were recognized as containing the lowest known forms of organic life.

Over thirty years have elapsed since these rocks were designated as forming the Azoic System, and the point at present at issue is, whether anything has been discovered in geology which renders this designation improper, unnecessary, or undesirable, or which justifies the adoption of either one of the terms "Laurentian" or "Archæan," or both, the question of the propriety of dividing the Azoic System into two or more groups being one to be examined farther on.

The introduction of the name "Laurentian" by the geologists of the Canada Survey has been already commented on, and it has been shown that this term, as first used by Mr. Logan, was the exact equivalent of the Azoic of Foster and Whitney. That being the case, the question of the propriety of this action on the part of the author of the new designation may be left to the good sense of the reader, who will judge for himself whether replacing a designation already in use by another one, previously employed by another geologist with a totally different

meaning, is a justifiable proceeding. And it will be noticed that any objection to the word Azoic, based on the ground that the formation in question had been found to contain organic remains, and therefore not to be properly called Azoic, was not in order at the time Mr. Logan introduced the term Laurentian, as it was not then pretended that these lower rocks were fossiliferous.

We proceed now to a discussion of the desirability of adopting the term Archæan, introduced by Dana; and, with this end in view, it will be necessary to look a little more minutely into the way in which it is used by this geologist. It will not have escaped the notice of the reader, however, that much in this discussion turns upon the question whether the so-called Azoic, Archæan, or Laurentian rocks are, or are not, destitute of traces of organic life. Hence, in order to clear the way for what is to follow, it will be well to take up this question at once.

To those familiar with the geological literature of the past twenty years, it will be evident that the only essential point before us is this: Is the *Eozoön* a "thing of life"? If it is not, then all the accessory evidence that the Archæan rocks are fossiliferous falls away of itself, as we shall endeavor to show, as being utterly intangible and unsatisfactory.

Without going into anything like a detailed account of the various publications issued by the Canada Survey, or under its inspiration, having it for their object to prove that there is a fossiliferous group of rocks below the lowest Lower Silurian (the Potsdam or Primordial), and of the discussion in regard to this point which has been going on during the past twenty years, we may content ourselves with giving a brief *résumé* of the facts connected with this rather remarkable chapter in the history of our geological progress.

Another name having been given by the Canada Survey to the rocks previously known as Azoic, it became desirable that the formation thus newly designated should be shown to be a fossiliferous one. For this purpose that problematical body now so well known under the name of the *Eozoön* was brought forward, and at the present time there exists quite a voluminous eozoönal literature.*

The first announcement in connection with the subject of the Eozoön was made by Mr. Logan, in his Report for the year 1858. In 1859 he exhibited specimens at the meeting of the American Association for the Advancement of Science, but went no farther at that time than to

* For a chronological catalogue of this literature, see "An Old Chapter of the Geological Record," etc., by W. King and T. H. Rowney, London, 1881, pp. ix–liv.

say that he was disposed to consider these specimens "as fossils." In 1864, Dr. Dawson, in his Address before the Natural History Society of Montreal, announced that he had "arrived at the conclusion that they [the fossils in question] are of animal nature, and belong to the very humblest type of animal existence known, that of the *Rhizopods*." He adds, that "the discovery of this remarkable fossil, to be known as the *Eozoön Canadense*, will be one of the brightest gems in the scientific crown of the Geological Survey of Canada." *

This preliminary announcement was followed by several elaborate papers, by Messrs. Logan, Dawson, and Hunt, published in the Quarterly Journal of the Geological Society, as well as others by Dr. W. B. Carpenter, published in the Proceedings of the Royal Society, in which it was claimed that the fossil in question was a *Foraminifer;* or, to use Dr. Carpenter's exact words, "that the *Eozoön* finds its proper place in the Foraminiferal series, I conceive to be conclusively proved by its accordance with the great types of that series in all the essential characters of organization, — namely, the structure of the shell forming the proper wall of the chambers, in which it agrees precisely with *Nummulina* and its allies; the presence of an 'intermediate skeleton,' and an elaborate 'canal-system,' the disposition of which reminds us most of *Calcarina;* a mode of communication of the chambers when they are most completely separated, which has its exact parallel in *Cyclodypeus;* and an ordinary want of completeness of separation between the chambers, corresponding with that which is characteristic of *Carpenteria*." †

From this time forward the Eozoön began to be an important matter. The authority of Dr. Carpenter, at first, bore down all opposition; and, with few exceptions, geologists and palæontologists gave this gigantic Foraminifer a place as the "earliest known representative on our planet of those wondrous powers of animal life which culminate and unite themselves with the spirit-world in man himself." ‡

Gradually, however, there came a reaction from the shock of this stupendous discovery, which first manifested itself in a denial, on the part of Professor Harkness (1865), of the organic nature of the Eozoön. This was followed in the succeeding year by an elaborate paper by Messrs. King and Rowney, in which they maintained that the *Eozoön Canadense* must be relegated to the inorganic kingdom. From this

* Canadian Naturalist, 1864, p. 220; Am. Jour. Sci., (2), XXXVII. 232.

† Quarterly Journal of the Geological Society of London, XXI. 64.

‡ Dawson, "The Dawn of Life," p. 1.

time forward, no year has failed to add something to the literature of this subject. But it must be admitted that the opponents of the organic character of the Eozoön have been on the whole decidedly in the minority. This problematical body has, almost without exception, gone into the various text-books of geology, in all countries where that branch of science is cultivated, with at most, in some instances, a vague intimation that there were some persons who were not disposed to accept the Eozoön as a relic of organized existence.

It was not an easy matter for those convinced that this body was simply a mineral to furnish satisfactory proof of the correctness of their opinion; for when it was said by them that they could discern nothing necessarily organic in the specimens of Eozoön which they had examined, it could always be replied, from the other side, that these opponents of the Eozoön had not had the opportunity of studying the series of specimens in the collections of the Canada Survey, and that these were so complete and convincing in character that every one to whom this privilege should be granted would be compelled to acknowledge that opposition to the views of Messrs. Dawson and Carpenter had no basis of fact.

In 1875, however, Professor Möbius of the University of Kiel, having discovered a Rhizopod, to which he gave the name of *Carpenteria Rhaphidodendron*, and which appeared to him, at first, to have an astonishing resemblance in its structure to that of the Eozoön, determined to make a thorough investigation of the Canadian supposed fossil, and, for this purpose, solicited material from all quarters. As he appeared to be, if not convinced, at least quite desirous of being convinced, of the organic nature of the Eozoön, he was supplied with all the best material in the hands of Dawson and Carpenter. Indeed, the latter, as Professor Möbius states, gave him one thin section, which he had never before allowed to go out of his hands, on account of its furnishing such important evidence of the organic nature of the Eozoön.*

The work in which the results obtained by Professor Möbius are given to the world is remarkable, especially, for the number and clearness of the illustrations which accompany the text, and they are of

* "Professor Carpenter hatte die grosse Güte, mir vortreffliche Präparate zu schicken; ja, er vertraute mir einen Dünnschliff zum Studium an, den er seines hohen beweisenden Werthes wegen noch niemals aus den Händen gegeben hatte." Möbius, in "Der Bau des Eozoon Canadense," etc., p. 177. In spite of this, we find Dawson claiming that the results obtained by Möbius should not be accepted as valid, because the latter "had access merely to a limited number of specimens." Am. Jour. Sci., (3), XVII. 197.

special value as allowing every one to see for himself just what the specimens amounted to, which were held by Carpenter and Dawson to furnish full evidence of the organic character of the Eozoön. The exact position of Professor Möbius when he began the investigation, and the result to which he attained, can be easily made out from the following sentence, in which the whole thing is summed up in a few words: "I began this investigation with the hope that I should succeed in proving, beyond possibility of doubt, that the Eozoön was organic. The facts, however, led me to the opposite conclusion."*

The value and importance of the investigations of Möbius have been acknowledged by Zittel, who thus expresses his opinion of the nature of the Eozoön: "In spite of the repeated answers of Dawson and Carpenter, this long struggle to maintain the organic nature of the Eozoön may well be admitted to have been brought to an end, and with a result unfavorable to that view, by the exhaustive memoir of Möbius." To this emphatic testimony on the part of Zittel may be added the equally positive statement, to the same effect, of the eminent palæontologist, F. Roemer, who thus states the case: "Finally, Möbius undertook an exhaustive microscopical investigation of this body [the Eozoön], in carrying on which he was able to make use of the best material in the possession both of Dawson and Carpenter, and he reached the positive and unquestionable result [sicheres unzweifelhaftes Ergebniss] that the supposed *Eozoön* is simply an inorganic formation [Bildung] consisting of serpentine and chrysotile in limestone. Consequently, by far the larger majority of geologists and palæontologists will consider this question as definitively settled, and will be *all the more ready to do so, since the occurrence of a fossil of this character in the oldest crystalline limestone was, on general principles, in the highest degree improbable.*"†

It is believed that in this country no geologist or palæontologist of eminence has distinctly put himself on record as being opposed to considering the Eozoön as a fossil. We have, however, a statement of Professor Leidy — a high authority on the lower forms of animal life, and who at the same time is familiar with minerals — to the effect that he, in 1877, "was not fully convinced of its [the Eozoön's] animal nature."‡

Apart from the evidence so skilfully presented by Möbius, as well as by Carter, Rowney, and King, we have that of our own obtaining, and

* *l. c.*, p. 189.

† F. Roemer, Lethæa Palæozoica, 1880, p. 285.

‡ Proceedings of the Academy of Natural Sciences of Philadelphia, 1877, p. 20.

which we consider entirely decisive of the question, and in favor of the mineral nature of the Eozoön. The fact of the occurrence of the so-called "eozoönal structure" in some of the limestone deposits of Eastern Massachusetts has been repeatedly admitted both by the advocates and the opponents of the organic character of this peculiar body.* By most geologists these calcareous masses have been considered to be interbedded with and an original portion of the formation, and supposed to be beyond doubt of sedimentary origin.

In 1871, however, after a careful study of the eozoönal limestones of Chelmsford, Bolton, and Boxborough, Mr. L. S. Burbank claimed that these were not true stratified deposits laid down with the gneiss, but of subsequent formation to that rock, and of vein-like character; and that, in consequence of this, the Eozoön must be of mineral, and not of animal origin. These views were sustained by Messrs. W. H. Niles and J. B. Perry, — the latter extending his observations so as to include the locality at Newbury. Mr. Burbank gave figures illustrating the mode of occurrence of the limestone, and these seemed to furnish strong evidence in support of his views.†

Most of these localities have been studied by us, with especial reference to the origin and mode of occurrence of the calcareous material. At Stoneham, the limestone was found to occur in an indurated argillite, which is cut through by dikes of diabase (diorite), etc. The calcareous mass, lying approximately in the direction of the strike of the enclosing rock, frequently cuts across its lamination planes, so as to include masses of the argillite; and portions sometimes extend for a considerable distance across the stratification, so as to have the character of fissure veins. The limestone is entirely crystalline, and shows upon its borders that intense chemical action has there taken place, as it is greatly altered and filled with epidote and such other silicates as are ordinarily found resulting from conditions of the kind here suggested. While one of the dikes was seen to intersect the limestone, others were found to have been cut off by it. These latter dikes abutted directly against the limestone, and along the line of junction of the two rocks were the same evidences of intense chemical action which were seen at the edge of the calcareous mass in other places.

From this it follows that this limestone is a segregated or vein-like deposit, of earlier date than some of the dikes, but posterior to the

* See *ante*, pp. 411, 419.

† Proc. Bost. Soc. Nat. Hist., 1871, XIV., 189–204; Proc. Amer. Assoc. Adv. Sci., 1871, XX., 262–266, 270–276.

time of the formation of the larger portion of them. It would seem from these observations that the calcareous mass was the result of the action of thermal waters during the time of the dying out of the volcanic forces which have been shown to have formerly been active in Eastern Massachusetts.*

The limestone localities at Chelmsford, so fully described by Mr. Burbank, were also carefully examined by us. They are included in gneiss, and are extremely irregular, sometimes coinciding in direction with the lamination of the enclosing rock, and at other times cutting across it. So irregularly are the gneiss and limestone locked together that their relations to each other could, in our judgment, only be explained by admitting that the calcareous material is a segregated deposit. This "eozoönal" limestone is entirely crystalline, and filled with scapolite, actinolite, and other silicates; while the Eozoön is most abundant and best preserved in the most decidedly crystalline portions of the calcareous deposit. No dike was seen to be cut by the limestone; but one, of melaphyr, about two inches wide, was seen traversing it.

We have also studied the deposits of limestone in Newbury, known as the "Devil's Den" and "Devil's Basin." The relations of the calcareous mass to the enclosing rock at these localities are very similar to those already indicated for the others, and do not allow of explanation in any other way than by admitting that the limestone is a segregated deposit. The evidences of intense chemical action are here also plainly revealed by the presence, in the calcareous mass, of silicates, such as wollastonite and garnet. Moreover, the rock in which the limestone is enclosed — the country rock — is, as we think, an eruptive one, belonging with the older basalts, but of course much changed from its original character.

This view of the segregated nature of these deposits was, moreover, entirely freed from anything which it might have of a theoretical nature by our finding at Devil's Basin — the locality in which the Eozoön occurs — that the country rock was cut by dikes of eruptive rock, which squarely abutted against the limestone on the side without intersecting it. Also, the ends of the dikes next to the limestone showed the same intense chemical action and resulting secondary silicates that the country rock in like position does. All this indicates, in the most unmistakable manner, that the country rock was formed, and that dikes traversed it, *before the limestone was there.* In short, the calcareous mass has been introduced since the formation of the enclosing

* Harv. Univ. Bull., No. 22, pp. 359, 360.

rock, and consequently could not by any possibility be an original contemporaneously bedded structure; neither could it be fossiliferous, any more than an ordinary veinstone could so be.

For the purpose of accounting, to a certain extent, for the extraordinary delusion which has prevailed among palæontologists with reference to the organic character of the Eozoön, a few words may here be added. In the first place, attention may be called to the fact, that the discovery of traces of organic life in such rocks as lavas and granites, and even in slags and meteorites, has become one of the common occurrences of the present day. A long list of names might be cited of scientific observers who have enriched geological literature with "gems" of this kind. The reasons of this are in part to be found in the desire to do something sensational, and in part to the entire ignorance which prevails among many zoölogists and palæontologists as to the great variety of forms occurring in the mineral kingdom, which it only requires an imaginative temperament to endow with the attributes of organic structure. Symmetrical grouping of minute crystals, dendritic markings, radiated aggregations, fibrous structure, and many other commonly occurring forms in which minerals are found, have, each in turn, served as a basis for a new genus, family, or order in the animal or the vegetable kingdom.

A complete list of all the books and papers which have appeared within the past twenty or thirty years, — that is, during the latest epoch of geological enlightenment, — having for their object the display to the scientific world of dazzling "gems" of the Eozoön family, would form quite a lengthy document. Space can only be found for alluding to a few of these which are of special interest as bearing — more or less directly — on the Eozoön question, either as showing how the sponsors of this supposed organism have allowed themselves to be deceived in other and parallel cases, or how far, in general, those can go who have once taken up the idea that the peculiar mineral forms with which they are unfamiliar, and which have a superficial resemblance to the work of living organisms, are really such.

As Dr. W. B. Carpenter is the person who, more than any one else, is responsible for the generally prevailing belief in the organic nature of the Eozoön, it will be well to call attention, in the first place, to a communication of this eminent authority, published in "Nature," and headed "New Laurentian Fossil." In this he remarks, in reference to a specimen furnished him by a gentleman who had been "for some years on the outlook for fossils in the Laurentian rocks of Scotland," as follows: —

"The fabric seems to have consisted of superposed layers of calcareous shell substance, whose continuity is frequently interrupted. . . . . The state of preservation of the fossil thus corresponds exactly with that of the Silurian Stromatopora, to which, indeed, it bears a strong general resemblance. . . . . The shelly layers are as distinct in character from the calcite contents of the chambers, as are those of the Nummulites of the pyramid-limestone with which they agree in their remarkable hardness, corresponding with that of porcellanous shell. Altogether I have no hesitation in concurring with Prof. H. A. Nicholson, Prof. Geikie, and Mr. Etheridge in affirming it to be so unmistakably organic, that, if it be claimed by mineralogists as a 'rock structure,' a large number of universally-accepted fossils will have to go along with it. As it is *essentially calcareous* in its composition, there is no room for the hypothesis of its production by the process of 'mineral segregation,' which is maintained by certain mineralogists . . . . to have been adequate to the production of the alternating layers of serpentine and calcareous shell-substance in the Canadian *Eozoön*. And though mineralogical analysis might not improbably detect small particles of various minerals in its substance, their presence no more establishes its claim to be regarded as a mere rock structure, than does the presence of siliceous films . . . . in a piece of coral-limestone." *

Some weeks later Dr. Carpenter acknowledged that the fossil thus elaborately described by him was *not calcareous*, but that it consisted "of alternating layers of feldspar and quartz — the former simulating an organic structure like that of Stromatopora, and the latter occupying what had been supposed to be the cavities of that structure — *together constituting what is known to petrologists as 'graphic granite.'*" †

In this case, however, Dr. Carpenter might claim that, having made a mistake, he was ready and willing to withdraw his statements after he had been shown to be in error; and that, having done this, the value of his testimony in regard to the Eozoön was not thereby impaired. As an offset to this, we will proceed to show that in the case of one of the fundamentally important features of his supposed Foraminifer he was also as much mistaken as he was in regard to the graphic granite, and that he has admitted himself to be so; but that he did not make this admission until after having persisted in his error for many years, so that we are left entirely in the dark as to how long we must wait before being able to find out what his final opinion will be in a matter of this kind. The point is this: Dr. Carpenter, after having, at various times during an interval of fifteen years, called attention to the so-called "proper wall" or "nummuline layer" of the Eozoön, the existence of which he said that he had been able "*most satisfactorily to determine*," and which he considered to be "*a point of the highest importance in the determina-*

* Nature, 1876, XIV. 9. † Ibid., 68.

tion of the affinities of Eozoön," * has recently admitted that he was entirely mistaken in all this, and has conceded the fact claimed by the opponents of the organic character of this supposed fossil, that this nummuline layer was simply the mineral chrysotile in one of its ordinary forms of occurrence, namely, in bands or layers of finely fibrous material.†

In describing certain rocks of New Hampshire called by him "greenstones," and assigned to the Huronian formation by Prof. C. H. Hitchcock, Dr. Hawes made the following statements: —

"In the microscopic study of these massive chloritic rocks, or metadiabase, I have found certain forms which appear to be of organic origin. . . . . It has the structure of a tabulated coral, resembling much a *Chætetes;* but on account of its minuteness, in connection with other characters, there is little question but that it is a fragment of a rhizopod mass or foraminifer;‡ and a close resemblance to a *Stromatopora* will be noticed. . . . . These forms seem to be abundant in the rock. . . . . The specimen figured is the most perfect that I have seen; but smaller fragments are abundant, and as they are apparently alike in dimensions, they sustain the supposition of the organic origin of all. . . . . These forms, distributed through the massive rock, have a structure, ... which cannot be attributed to crystallization. They seem to make it evident that rhizopods must have been living over the sea bottom during the accumulation of these sediments, and became buried in the mud which is now the material of the rock. These forms are composed of silicates. . . . . Yet upon placing a drop of acid upon one of them it effervesced for a short time, showing that carbonate of lime existed in it — perhaps part of that of the original foraminifer.

"The presence of these remains of rhizopods in the metadiabase is additional evidence of the sedimentary origin of these rocks; and they also confirm the view that the metamorphism was feeble in its degree, since it allowed of the preservation of these forms. . . . . Everything points to quiet waters during the original deposition,§ and finally to gentle metamorphism." ‖

* Quart. Jour. Geol. Soc., XXI. 62.

† This retraction, on the part of Dr. Carpenter, of one of the most essential features of the Eozoön has not, so far as we know, been published; but it was made in public at a meeting of the Boston Natural History Society, and repeated in private at the Museum in Cambridge, in presence of one of the authors of this paper.

‡ The reader will be tempted, at this point, to exclaim with Dr. Carpenter, "Truly, as I have had occasion before to say, 'there is no limit to the possibilities of Foraminifera!'" (Nature, XIV. 9.)

§ It may be said that these rocks have been examined by Dr. Wadsworth, and their microscopic characters found to be identical with those of the altered diabases of Eastern Massachusetts, which occur in unmistakable dikes, cutting argillite (Primordial?). The field evidence, Mr. Huntington states, indicates that Hawes's rocks were in dikes.

‖ Am. Jour. Sci., 1876 (3), XII. 129–137.

The supposed fossils were examined by Principal J. W. Dawson, who pointed out their resemblance to parts of Hydroids, Bryozoans, Entomostracans, and some Devonian plants, or lastly to some supposed Laurentian fossils of Gümbel. He also says: "On the whole, though these objects are unlike any purely mineral substance with which I am acquainted, and are probably fragments of some organic body, I do not think it possible at present to indicate with any certainty their probable affinities." * These fossils also appear to have received Dr. Hunt's indorsement.†

Later, Dr. Hawes, having in the mean time studied in Europe, frankly acknowledged that his supposed fossils were simply the alteration products of titaniferous iron, stating: "The other gentlemen who have seen these specimens, and have published opinions in reference to them, are very excusable, on the ground that they [Dawson and Hunt] saw but single specimens, and are not professed experts in microscopic mineralogy. The author has paid some attention to the subject, under competent instruction, since the paper referred to was published." ‡

In view of what has been stated above, it would seem that Messrs. Dawson and Carpenter ought not again to claim to have any right to the expression of an opinion on points like those involved in the question of the organic character of the Eozoön, since they have both shown themselves entirely unacquainted with elementary mineralogy and lithology.

Of all the upholders of the organic nature of the Eozoön, there is no one whose work is so curious and instructive — from the point of view of one desirous of ascertaining how far the determination to find traces of life in everything can carry an observer — as is that of Otto Hahn. This author is an entire believer in the organic character of Eozoön; but is surprised that any one should be so blind as not to recognize that it is a plant.§ Fifteen different plant forms are described by him as made out from his Eozoön sections, and each is gifted with a distinct name. One animal appears to have had the exclusive range of this wonderful vegetation, the *Titanus Bismarki!* The title of the work in

* Am. Jour. Sci., 1876 (3), XII. 395.

† Proc. Am. Assoc. Adv. Sci., 1876, XXV. 208.

‡ Geology of New Hampshire, III., Part IV. pp. 40, 41; Am. Jour. Sci., 1878 (3), XVI. 396.

§ "When I now look through my thin sections and find in them the plainest evidences of reproductive cells (Brutzellen) belonging to the plant, ... I am obliged to believe that all those who worked at the Eozoön, myself included, were smitten with blindness." (Hahn, Die Urzelle, etc., p. 19.)

which all this is revealed is as follows: "The Primeval Cell, together with the Proof that Granite, Gneiss, Serpentine, Talc, certain Sandstones, also Basalt, and finally Meteoric Stones and Meteoric Iron, consist of Plants." This is only the carrying a little farther of the same style of observation as that to which we are indebted for the Eozoön, and that some one should follow this line of research to the highest pitch of absurdity seemed to be the one thing wanting to give the Eozoön the *coup de grace.*

As already mentioned, it is held by Dana, as well as by many other geologists, that the occurrence of limestone in the Azoic series is evidence of the existence of life at the time of its formation. The same view is also maintained with reference to the presence of graphite in these rocks. In upholding these views it is the authority of Bischof which is chiefly followed. This author, in his classic work on chemical geology, declares in the most positive manner that those geologists who believe that the earth has cooled from a condition of igneous fluidity cannot do otherwise than admit that all the carbon on and in the earth is of secondary origin, that is to say, was not present in the primeval earth (in der Schöpfungsperiode nicht vorhanden war). The statements which he brings forward to sustain this view are, however, not correct.

The first of these alleged facts is, that carbon could not have existed in contact with the oxides of iron and the other metals in a melted magma, because it would necessarily have been oxidized to carbonic acid and carbonic oxide.* In answer to this it may be stated, that, if graphite cannot exist, it certainly can be formed, under these conditions, since it is a well-known fact, daily witnessed by those engaged in blast-furnace operations, that this material separates out in distinct crystalline plates and scales from the melted iron as it cools; moreover, the presence of graphite in furnace slags is a matter of not infrequent occurrence. The presence of graphite in the metallic iron meteorites may also be mentioned in this connection, as strong evidence that carbon can exist in connection with melted iron, or be in some way separated from it. This graphite occurs in some cases in nodules completely enveloped in the metallic mass. In the iron-bearing basalts of Greenland, graphite is also found both in the metallic iron and in the basaltic rock, in which this metal is enclosed.†

* Bischof, Jahrbuch der chemischen und physikalischen Geologie, 2d edition, I. 662, 663.

† See Törnebohm, in K. Svenska Vet. Akad. Handlingar, Band V. No. 10; also, Daubrée, Géologie Experimentale, p. 555. Lawrence Smith, Mémoire sur le Fer Natif du Groenland, in Ann. de Chim. et Phys., (5), XVI. 452–505.

Furthermore, Bischof states as additional evidence of the truth of his assertion that carbon cannot have existed in the primeval earth, that this element is not found in the unstratified crystalline rocks which, according to the views of the plutonists, were lifted up from beneath. ("Da die ganze Gruppe von nicht geschichteten krystallinischen Gesteinen, welche nach Ansicht der Plutonisten von unten heraufgehoben werden, in ihrer Masse keinen Kohlenstoff enthalten," etc.)

This, again, is an entire mistake on the part of Bischof. The largest and most important deposit of graphite in the world — that of the Alibert mine — is described by various geologists who have seen it as occurring in granite, or as lying between granite and syenite. In fact, the normal occurrence of graphite may be said to be in the older gneissic and schistose rocks, in which it either forms lenticular masses of greater or less size, or is disseminated through the rock in scales, or thin layers.

One of the most celebrated known localities of graphite is in Bavaria, in the so-called Passauer Wald, where it has been for a long series of years extensively worked. Gümbel has made a thorough investigation of this region. The rock in which the graphite is contained is gneiss, called by this geologist "Graphitgneiss," because the mineral in question is disseminated through the rock just as the mica is, forming apparently an integral part of it; not — as Gümbel thinks is evident — replacing the mica, but being an original constituent of the gneiss. To use his own words: "We must therefore consider the graphite to be as much a primary formation [primäre Bildung] as are the other minerals of the gneiss, of which it makes a constituent part."

Graphite occurs in the crystalline limestones associated with the older crystalline or azoic rocks; but not — so far as we know — aggregated into masses of sufficient size to be anywhere an object of profitable exploration. The normal mode of occurrence of graphite in limestone seems to be in the form of thin scales disseminated through the rock, and these scales are larger and more distinctly developed where the limestone is most crystalline.

Indeed, so far are the statements of Bischof from the truth, that it may be stated, as the result of geological observation up to the present time, that true graphite is "almost exclusively confined to granite, gneiss, quartz, mica-slate, crystallized limestone, and the older slates."*

That graphite has been formed from vegetable matter, at least in a manner similar to that in which coal has been, as is claimed by so

* Jukes and Geikie, "The Student's Manual of Geology," 3d edition, 1872, p. 56.

many geologists, seems to us in the highest degree improbable, for the reason that true graphite has never been found — so far as our knowledge goes — in connection with coal, whether the latter be in its ordinary bituminous condition or in its nearest approach to pure carbon as anthracite, as it ought to be if it was formed in the same way in which coal has been, and was only the carrying forward of that process to the last stage of carbonization. If graphite was the final result of the working of the agencies by which vegetable matter has been turned into anthracite, it seems impossible that, somewhere in the vast area covered by the anthracitic formation in this and other countries, there should not be at least some distinct traces of graphitic material found.

It is stated in the various text-books of mineralogy and geology, that graphite has been formed by the passage of dikes of eruptive rock through coal beds. This, however, does not seem to be confirmed by the result of more recent and more careful observations than those made in the days to which many of the statements in our text-books belong. So far as our own observations go, the tendency of the eruptive rocks, in their passage through coal, is to change this into a material very different in character from graphite.

Much of what is called "plumbago" is by no means graphite. It is, rather, a mixture of particles of carbonaceous matter with rock; the result being, in certain cases at least, a refractory material which can be used for some of the purposes for which graphite is employed. We repeat, therefore, that we have never seen, and know of no authentic account of any one else having seen, pure graphite and coal so associated together as to make it necessary to believe that the former was produced by the decomposition of vegetable matter, as we have abundant reason to believe that coal in all its forms has been.

The graphite which is formed artificially at the present day is, so far as we know, exclusively the result of operations carried on at a high temperature.* The separating out of graphite in cast-iron and slags,

* The same may be said of the more or less successful attempts to make artificial diamonds. The experiments of Mr. Hannay in this line, in which he claims to have succeeded in forming this gem, although by no means affording any encouragement for the belief that it can be manufactured with pecuniary profit, seem to have resulted in the production of something which had the physical characters of the diamond. High temperature and immense pressure were the most important factors; but it is stated by Mr. Hannay that the presence of nitrogen seemed to be a *sine qua non*. This last-mentioned item may be noticed in connection with what is said farther on in the text in reference to the part played by cyanogen in the formation of artificial graphite.

and the formation of the material in gas retorts, are striking instances of this.

The most abundant source of artificial graphite, however, is in connection with the manufacture of soda by the Le Blanc process; for here the quantity produced is so large that it has been seriously proposed to use it for the manufacture of lead pencils. This graphite, according to R. Wagner, is formed at a certain stage of the process of converting the caustic soda into the carbonate; at which time the cyanogen present — which must have resulted from the preceding treatment of the saline mass at a high temperature in the reverberatory furnace — undergoes decomposition, the carbon separating out in the form of graphite. The same origin is claimed by Wagner for the graphite occurring in cast-iron. According to him, it is not the carbon, dissolved in the iron itself, which separates out when the latter cools and solidifies, but that which is derived from the decomposition of the cyanides present in large quantity in the iron as well as in the slag. These cyanides undergo decomposition, the carbon appearing as graphite, and the nitrogen going off in the form of ammonia, well known to be one of the products of blast-furnace operations.*

Thus it appears that we know of no other way in which graphite can be artificially formed than indirectly in connection with, or as one of the results of, some process or operation carried on at a very high temperature.

The position assumed by Bischof with reference to the diamond is also based on imperfect knowledge of the facts connected with the occurrence of this most remarkable substance. It was Bischof's idea that the diamond was formed in the superficial detrital material of recent age, in which this gem had until within a few years been exclusively found. He believed that it was simply a result of the decomposition of organic matter, under conditions which prevail everywhere; so that, if his view were the correct one, the diamond, instead of being the most precious of gems and being found in exceedingly minute quantity, should be literally "as common as dirt."

The facts in regard to the diamond, from the standpoint of our present knowledge, are simply these: Wherever detritus of crystalline rocks occurs unconsolidated, so that it can be cheaply "handled," — that is, moved and washed, — there gold either has been in former times or is now being obtained, although not by any means always in remu-

* See Sitzungsberichte der phys.-med. Gesells. zu Würzburg, 1869, p. xxii.; also, Wagner's Jahresbericht, 1872, p 57.

nerative quantity. Most of these detrital deposits, where rich enough to pay for working, have already been washed over, and have become exhausted of their gold. Those which are still the object of exploitation on a large scale usually produce diamonds as well as gold; as, for instance, Australia and California, not to speak of the less important Appalachian gold-fields. It is true that the quantity of diamonds thus produced is very small, so that there would not be the slightest probability that the auriferous gravels could ordinarily be worked with profit for this gem; although we have reason to believe that by the common methods of gold-washing much the larger proportion of the diamonds would be lost or passed over unseen. Still, we are obliged to admit that the diamond must originally have had its birthplace in the same crystalline rocks from which the gold has been derived, and out of whose detritus both these precious substances are washed. There is no more reason to suppose that the diamonds were formed in the gravel posterior to its abrasion from the solid rock than that the gold was.

The occurrence of the diamond in Brazil, in the detrital formations, in no respect differs from that indicated for California and Australia, except that these are localities where this gem is unusually abundant, and where the detrital material is more ferruginous than it ordinarily is. The diamonds have been deposited in a modern gravel, made up of the ruins of a much older crystalline formation; and this gravel has been, in places, reconsolidated into a rock by having become impregnated with a ferruginous solution. Whether the diamonds came originally out of the crystalline metamorphosed sedimentary rocks, or out of the eruptive masses with which these are associated — the eruptive material often predominating very largely over the sedimentary: this we know not, as the diamonds are always found loose, in crystals, and separate from any of their original matrix.

In fact, it is only within a few years that we knew anything definite about the occurrence of the diamond in its original matrix. The locality we refer to is, of course, South Africa, where this gem occurs, within certain well-defined limits, in much larger quantity than was ever before known. But here the matrix, or enclosing rock, is unquestionably eruptive. It not only has the mineralogical characters of an eruptive rock, but the whole style of its occurrence is such as to stamp it as unmistakably volcanic. Everything about the South African diamond-bearing localities is remarkable and exceptional; and thus far the theory of the origin of the diamond has been but little advanced by the observations made in that region. All that can safely be said

is, that it seems as if the idea that a high temperature had been one of the factors in the mysterious operation of making the diamond had received a certain additional amount of corroborative evidence in consequence of the association of that gem with volcanic materials in the most productive diamantiferous district the world has ever known.

That the conditions under which this precious gem has been formed are very exceptional, can be safely inferred from the extremely small amount of the material which has been originated. Not that the diamond is limited, or almost exclusively so, to one locality, like certain minerals, — as, for instance, cryolite and red oxide of zinc. It occurs, on the contrary, all over the world, but never — so far as yet observed — in masses weighing more than a few hundred grains; while, if all the specimens of this gem which go to help make up the crown-jewels of all the empires and kingdoms of the world were put together, their united weight would certainly not exceed a few pounds.*

The inference from that which has been stated above is, that we are not justified in assuming that the occurrence of graphite in the azoic rocks is a proof that this material has resulted from the action of organic agencies, or, in other words, that life existed on the globe at the time these rocks were deposited. The fact that no recognizable traces of such life have ever been found in connection with the graphite of the Azoic series, is decidedly an important item in this connection; and we consider that geologists are not justified in assuming the presence of life when they not only have no positive evidence of its existence, but when the theoretical probabilities are strongly in opposition to this view.

The idea that the presence of carbonate of lime must necessarily be taken as a proof of the former existence of life — as is so positively asserted by Bischof, Dana, and many other geologists — seems to us entirely at variance with the facts. It is impossible for any one familiar with the mineralogical occurrence of carbonate of lime to deny that the formation of this material is a process which is going on, in innumerable localities and on a grand scale, without the intervention of organized existences.

Every metalliferous vein is likely to have, and in many instances such veins do have, the metallic sulphides which they contain — sulphur being by far the most common mineralizer of the metals — more or less completely converted into carbonates at their outcrops. Thus, while chalcopyrite is the most common ore of copper, the carbonate of

* The total weight *in the rough* of thirteen of the largest and most celebrated diamonds in the world was only a little over a pound.

the oxide of this metal is very frequently found, and sometimes in large quantity, in and near the outcrop of such veins. Water takes carbonic acid from the air, and, percolating downwards, converts a great variety of mineral substances more or less completely into carbonates. This is a process which may be said to be going on everywhere on a grand scale.

Calcareous spar (calcite) is one of the most common of veinstones, occurring in very large masses, both in regular veins and in those masses which belong to the segregated form of metalliferous and mineral deposits.

Again, carbonate of lime, or of lime and magnesia, is among the most commonly occurring products of the alteration of eruptive rocks.

Much of the crystalline limestone, or marble, which occurs in the Azoic series, seems to us to belong to the segregated form of occurrence. Some of it is certainly of this character, as has been already mentioned in connection with the question of the organic character of the Eozoön. If any of it is really bedded limestone — that is, rock which was formed contemporaneously with the formation of the beds with which it is associated — it seems to us clear that there are stronger reasons for believing that this has been the result of a chemical precipitation, than that the calcareous material has been formed through the agency of life.

In default of other evidence of the presence of the results of organized existence in the azoic rocks, it has been maintained by some that the occurrence of ores of iron in extraordinary quantity in that series furnished the desired proof. The facts are, however, that some at least of the iron thus occurring is of eruptive origin; that the oxide of iron is a mineral commonly and abundantly found making an essential component of volcanic rocks; that metallic iron is so found in large quantity, — in one region, at least; that there is strong reason for believing that metallic iron forms, if not the whole, at least a large part, of the earth's interior; and, finally, that a large portion of the material which comes to us from outside our planet is metallic iron. All this, we think, is amply sufficient for a refutation of the theory, that the presence of the ores of iron is a proof of the existence of life at the time when the rocks were formed in which those ores occur.

That it should be seriously maintained that the presence of sulphur is evidence of the presence of organic agencies, seems to us still more extraordinary than that the ores of iron should be so regarded. Sulphur is one of the most abundantly diffused of the elements. The sulphu-

rets of the various metals occur all over the world in vast quantity, and as low down as mining has ever penetrated. The facility with which the metallic sulphurets are decomposed by water when at a high temperature, and again the liability to decomposition, in a variety of ways, of the sulphuretted hydrogen thus formed, are matters familiar to those who are moderately well acquainted with elementary chemistry. We need, in this connection, only state the simple fact, that, only a few years ago, nine tenths of all the sulphur consumed in the world was obtained from a region where all the facts show clearly that this sulphur was the result of volcanic agencies. This alone is sufficient evidence on the point in question.

It has also been claimed that the presence of apatite in the Azoic rocks was an indication of the existence of life at the time these rocks were deposited. Since phosphoric acid, probably largely in the form of phosphate of lime, has been found in almost every kind of eruptive rock, including granite, porphyry, and both ancient and modern lavas, it seems that the theory which makes this mineral necessarily the result of organic agencies, is not supported by facts. The earliest plants and animals which required phosphoric acid for their development cannot have taken it originally from the atmosphere, since it does not exist there. They must, therefore, have obtained it from the earth, unless we are willing to admit that it was created by them.

In view of all that has been set forth in the preceding pages, we consider that we are fully justified in saying that the results of geological investigation during the past thirty-five years have given no encouragement to the idea that below the well-known Primordial zone — the Potsdam sandstone of American geologists — there is another series of fossiliferous rocks. We think that the nomenclature of the formations should be made to correspond with the actual facts, rather than with views which have no other than a theoretical basis. It would no doubt be in harmony with the ideas and wishes of many palæontologists, that there should be found a series of rocks occupying the position of the Azoic system replete with organisms of a lower type than that of the "Primordial Fauna" of Barrande.* This desire has, no doubt, powerfully contributed to the general acceptance of the Eozoön as a relic of life, although — as it seems to us — the entire absence of foraminiferal life in the lowest Silurian, throughout the world, places the

* "In his address to the British Association at Bath, he [Lyell] naturally revelled with delight at the discovery of the *Eozoon Canadense* in the Lower Laurentian." — Murch, in Geol. Mag., II. (1865), 98.

evolutionists who accept the Eozoön in a more difficult position than they would occupy if they rejected it altogether. It would be better for them to take the ground occupied by F. Roemer, and say that "the strata containing the Primordial Fauna are the oldest fossiliferous rocks, either because the rocks which are still older were originally unsuited to the preservation of traces of life, or had become so in consequence of subsequent changes, or else because the organisms which preceded the Primordial Fauna were of too perishable a character to be preserved." At all events, let them recognize, with Roemer, that, so far as our present knowledge goes, there are no fossils older than those of the Primordial Fauna.

Of all the results of geological and palæontological investigations during the past half-century, there is no one so remarkable as the revelation of the existence of the so-called Primordial Fauna. It is now clearly established that there was a time when life was represented by a few forms, which were essentially the same all over the globe. What has long been known to be true for Europe and America has been recently supplemented, for Asia, by the investigations of Richthofen in China, where the peculiar primordial fauna seems to be largely developed, bearing, as Professor Dames remarks,* "an astonishing resemblance" to that of North America and Scandinavia. We have, namely, in China, the same intermixture of trilobites, either belonging to the genus *Conocephalites*, or closely related to it, together with the usual primordial brachiopods, *Orthis* and *Lingulella*, which everywhere characterize the oldest rocks in which any "decipherable traces" of life have been found. And, as if in utter contempt of all theories, we find the trilobites disappearing entirely in early geological times, while the brachiopods remain almost or entirely unchanged up to the present epoch.

We have thus, as we think, clearly established the truth of the statement, that the stratified rocks designated as Azoic by Foster and Whitney, and included within the Archæan of Dana are — so far as present evidence goes — non-fossiliferous. A persistent search for nearly half a century, in all parts of the world, for traces of life in infra-Silurian formations has not resulted in success. We consider, therefore, that geologists who prefer the guidance of fact to that of theory, and who respect the law of priority in nomenclature, will continue the use of the name Azoic for the rocks described under that name by Foster and Whitney. At the same time, it is desirable that a more definite understanding should be

* China, Vol. IV. p. 7.

had as to the nature and age of the rocks to be designated by that term, with especial reference to the name "Archæan," introduced by Dana, as already mentioned, and which has of late years to a considerable extent replaced both the Azoic of the Lake Superior Survey and the Laurentian and Huronian of the Canada geologists.

Dana, in that edition of his Manual in which he first introduces the term Archæan, expressly says that "this formation [the Archæan] was first distinctly recognized in its true importance in the Report of Foster and Whitney on the Lake Superior region, where it was named 'the *Azoic system*,'" so that the natural inference would be that he intended his "Archæan" to be the exact equivalent of the "Azoic" of the Lake Superior geologists. As defined by him, however, this new designation has by no means the same signification as has the term which it was apparently intended to replace.

In endeavoring to ascertain, by examination and comparison of the statements made in reference to the Archæan in the latest edition of Dana's Manual, what rocks this author really did mean to include in that formation, we find considerable difficulty, so vague and contradictory are the expressions of his views on this point.

We are distinctly told, however, that "Archæan Time" includes "*the era in which appeared the earliest and simplest forms of animals*"; it also embraces, as we are informed, "*an era in which the physical conditions were incompatible with the existence of life.*" Thus it appears evident that the author of the term Archæan clearly intended to include under that designation a series of stratified fossiliferous rocks, and also other rocks, which preceded these in age, and were formed before life existed on the globe.

But we are informed by the same author, that the first appearance of life, of whatever rank that life might be, was an event of the highest interest in the geological history of the earth. We would go even farther than that, and say that it was an event far transcending in importance any other one which has ever taken place on this planet. And, bearing this in mind, we would insist that so great a transformation in the earth's condition should be recognized in our geological nomenclature. At all events, it would, as it seems to us, be in the highest degree unphilosophical to call by the same name rocks which not only differed in their geological age, but also in regard to the all-important point of having been formed before and after the introduction of life upon the globe.

The facts are, however, that the fossiliferous portion of Dana's

Archæan is only *theoretically* fossiliferous. He admits that "no distinct remains of plants have been found in it." Yet, as his theoretical views demand that plants should have existed before animals, he has no hesitation in asserting that the presence of graphite is "strong evidence that plants of some kind were abundant." He even goes so far as to state what these plants "must have been," namely, marine *Algæ*, lichens, and fungi. At the same time, although admitting that the Eozoön is a somewhat doubtful organism, he thinks that "animals of the lowest division of animal life *were probably abundant*" (in the Archæan).

If it be true, as Dana believes, that there existed, at a time previous to the epoch of the Lower Silurian, an abundance of animal and vegetable life, then the strata deposited at the time this life existed should be enrolled among the fossiliferous groups, with a special name indicating the relations which this life held to that of succeeding groups. They certainly should not be called Azoic, nor should they, on the other hand, be designated as Archæan, that name being used at the same time to include rocks necessarily destitute of traces of life and belonging to another epoch.

The truth is, however, that — so far as the present state of our knowledge goes — the *abundance of life* with which the Azoic is endowed is only a *theoretical abundance.* One could not well make a new palæontological subdivision based on graphite and calcite; hence the theoretically zoic rocks have had, of necessity, to remain with the practically azoic. Whenever a new fauna shall have been clearly recognized as actually existing below the Primordial, then the fact will no doubt receive welcome recognition, and the "Age" or "Epoch" be designated in accordance with the nature of the fauna thus made known.

Dana, however, not only includes in his Archæan the Azoic Series of Foster and Whitney, by him considered, on theoretical grounds, as being a fossiliferous formation; but he embraces under that designation, not only the granites and old volcanic rocks associated with the Azoic, and which took their present position before the lowest Silurian strata were deposited, but all eruptive, and indeed all crystalline rocks, with the exception of such as are the result of the metamorphism of strata of Silurian or post-Silurian age.

This is not only the necessary and logical inference from Dana's definition of the term Archæan, but it results clearly from his special designation of the rocks which he embraces under that name. The crust of the earth, according to his view, is Archæan; or, as he says, this is the

"only universal formation." He further remarks, that the Archæan rocks "extended over the whole globe, and were the floor of the ocean and the material of all emerged land when life first began to exist." Moreover, he expressly enumerates among the occurrences of Archæan rock those areas of the earth's crust "which, in the course of the upturnings of mountain-making, have been pushed upward among the displaced strata, and in this way have been brought out to the light."

Thus, according to Dana's definition of the term Archæan, it would be legitimate to include under that designation the granitic axis of the Sierra Nevada, although that mass of rock seems clearly to have assumed its present position at some time near the close of the Jurassic epoch. In fact we do not see how it would be possible not to admit that Ætna, for instance, belongs to the Archæan, as defined by Dana, since this volcano certainly consists of material which has been "pushed upward" during the process of "mountain-making," and which evidently formed a part of the exterior portion or crust of the earth.

The only way in which we could avoid designating all eruptive rocks, including those of which modern volcanoes are built up, as Archæan, would be by taking issue in regard to exactly what is meant by that frequently used term, the "crust of the earth." A discussion of this question would, however, lead to no very satisfactory result; for it is probable that hardly any two geologists would agree in their views, if required to set forth exactly what they considered to be meant by the phrase in question.

It is true that Dana does not follow out his own definition to its logical end; since he, for instance, speaks of the eruptive rocks of the Connecticut Valley, not as Archæan, but as Mesozoic. Others, however, seem to have taken his language as it would appear on the face of it to have been intended that it should be taken, and have called eruptive rocks of various ages Archæan, without any reference to the geological time of their appearance in their present position, but solely because they appear to have formed a part of the original "crust."

That this method of grouping and nomenclature is entirely unphilosophical, it seems hardly necessary for us to state. The first and most important question in geological research is always, To what period does the formation under investigation belong? If stratified, what geological age is indicated by the fossils it contains? If eruptive, at what time was it erupted? To class geological formations of different ages together is extremely undesirable, and can only be admitted when the treatment of the subject is a purely petrological one; as if, for instance, we should

speak of "sandstones," including those of all geological ages, but in such connection as would make the fact that the rock was sandstone the only point of importance with reference to the question under investigation.

We would then call the eruptive rocks associated with the Azoic, and which took their position in that formation before the deposition of the Palæozoic formation upon them, Azoic eruptive, designating the special rock by its lithological name. To the eruptive rocks of later date, we would respectively give the designation corresponding to that of the age or period when those rocks assumed their present position.

The granitic axis of the Sierra Santa Monica, therefore, is not an Archæan rock, but is a Tertiary eruptive, granitic, intrusive or axial rock, because it took the position in which we now see it during the Tertiary epoch.*

We come now to the second branch of our inquiry; namely, to the consideration of the question whether the Azoic series can properly be separated into two or more divisions, as has been done by the Canada Survey and by those who have followed its lead.

If we adopted the views and nomenclature of Dana we should at once admit that a division of the Azoic (Archæan) into two distinct groups was not only desirable, but imperatively necessary, since we can conceive of nothing more unphilosophical than placing stratified fossiliferous rocks in the same category with non-stratified and necessarily non-fossiliferous ones. To designate by the same term the stratified deposits of Lake Superior, which have remained as they now are since a time prior to the deposition of the Lower Silurian, and the eruptive granitic axis of a range which was not in existence until after the close of the Miocene Tertiary, seems to us entirely unreasonable, even from our own point of view, namely, that the Lake Superior rocks are in fact Azoic: how much more so, then, from the standpoint of Dana, who considers these same rocks to be fossiliferous!

If the Azoic rocks are really azoic, as we believe, then it follows, as

* Although some geologists and lithologists are unwilling to accept the fact of the occurrence of an axial mass of granitic rock uplifting rocks of Tertiary age, yet it is nevertheless true. Every feature which ought theoretically to characterize such an occurrence, if it had really taken place, is present in the section offered by the Santa Monica range. The sharp uplifting of the stratified beds in the immediate vicinity of the intrusive mass; the remarkable metamorphic action of the granitic central axis on the adjacent stratified deposits, and the return of them to their normal conditions at a distance from the cause of the uplift: all this is plainly to be seen, and there is but one explanation for the *ensemble* of the facts. — J. D. W.

a matter of course, that the series thus designated can only be separated into sub-systems on purely lithological grounds: if they are fossiliferous, as held by the Canada Survey, then it is equally clear that any subdivisions proposed for them should have a palæontological basis.

It is true that the Canada Survey did, for a time, uphold the idea that the Laurentian and Huronian were to be separated from each other on fossiliferous grounds, namely, that the one contained the Eozoön and the other did not; but this rather unsatisfactory basis of classification was soon abandoned. Later, it has been maintained by Mr. Murray, of the Newfoundland Survey,* that certain peculiar forms, supposed to be of organic origin, were characteristic of the Huronian of that region. Of one of these supposed fossils (the *Aspidella*) the palæontologist of the survey could only say that "its general aspect is that of a small *Chiton* or *Patella*"; but he hastens to add, that "it is not probable, however, that it is allied to either of these genera."† To us, the general aspect of the fossil in question, as figured by Mr. Billings, is that of a concretion intersected by small irregular cracks, and much more resembling the so-called *Septaria* than anything organic.

Specimens of *Aspidella* sent us by Mr. Murray, however, do not resemble in any respect the fossil figured by Mr. Billings. There are several indistinct impressions on the fragment of rock, neither of them like that fossil, and none of them necessarily of organic origin, at least so far as we are able to discover. They look more like spray markings than anything else with which we are able to compare them.

Of equally dubious character is the other of these so-called fossils, by which it is believed by the Canada geologists that the Huronian can be separated from the Laurentian. We refer to the *Arenicolites spiralis*, mentioned by Mr. Billings in the "Palæozoic Fossils,"‡ of which no description is given by him, it being only said to "occur near St. John's, in the Huronian." It is added, however, that "a more detailed description will be given hereafter." The real nature of this supposed fossil has already been sufficiently indicated by Dr. Wadsworth.§ Whether the *Arenicola didyma*, and the *Arenicolites sparsus*, of Salter, are or are not of organic origin, it is unnecessary here to inquire. That palæontologist considers them "burrows of annelides." We see little resemblance between these forms as figured by him and the *Arenicolites* of the Canadian Survey.‖

* See *ante*, p. 380.

† Geological Survey of Canada, Palæozoic Fossils, Vol. II. Part I. p. 77.

‡ *l. c.*, p. 77. § Science, I. 39.

‖ A large number of specimens of the *Arenicolites* were collected by Dr Wadsworth in the vicinity of St. John's.

In the latter we see no indication that anything possessed of life had to do with their formation. The *Arenicola* is mentioned by Zittel, together with many other equally problematic bodies, which that eminent palæontologist dismisses with the remark that "these names have no zoölogical significance."*

Since palæontology affords no assistance in dividing the Azoic (Archæan or original Laurentian) into two or more sub-systems, it remains to be seen what does justify such a division: and here a few remarks in regard to systems in geology will be desirable. No fact is better or more generally recognized than this: that geological time can only be kept by the aid of palæontology, the entire systematic classification of the formations, and their separation into "ages" and "epochs" being exclusively based on the order of succession of organic life. No one would think of defining the period of a geological event by saying that it took place in the "sandstone epoch," or in the "limestone epoch." But this is, in point of fact, essentially what has been sought to be done in dividing up the Laurentian first into two groups, the Laurentian and Huronian, and afterward into various other subdivisions, as shown in the preceding pages. Such subdivisions, when the work has been well done and the order of superposition of the rocks correctly determined, may be of value, but only of local value, and they must be recognized as having no claims to be considered generally applicable to all regions.

To what depths of confusion geologists have descended in their endeavors to make out a distinct order of succession in the various lithological developments of the Azoic, and in their determination to uphold the divisions introduced by the Canada Survey, must have been made thoroughly apparent by what has been given in the preceding pages. We have seen the rocks moved about, from year to year, like the pieces in a Chinese puzzle, in a vain attempt to create the desired figure. And when to a false theoretical basis has been added entire incompetence in matters of geological observation and lithological determination, the confusion which has resulted has — as has been shown — become something almost incredible.

We may now proceed to consider, a little more in detail, how such methods as have been shown in the preceding pages to be current in the study of the crystalline rocks have come into vogue in this country, and to some extent abroad. That this has taken place largely through the influence of the Canada Survey under its old organization, it is thought

* Zittel, Traité de Paléontologie, Tom. I., 1883, p. 576.

no one will deny; and for the purpose of throwing light on the origin of the methods in question we naturally seek to ascertain what were the principles by which that survey was governed. No one conversant with the history of that organization will doubt that its methods and purposes were arranged and formulated by the geologist who was its head during the first twenty-seven years of its prosecution: that none of his subordinates did originate them, may readily be inferred from the fact that the second in authority had been trained as a midshipman, having previous to his joining the survey had no other experience than that gained on the Ordnance Survey of Great Britain, while he remained essentially an explorer and a stratigraphical geologist in all his methods. That the one who for so many years served as the mouthpiece of the Canada Survey did not prescribe its methods, can be readily inferred from his own statement,* that, for "official reasons," he did not dissent from Logan's views, the correctness of which he for many years doubted; and from the fact that at the very time when he says he did not believe in these opinions he was warmly supporting them in print. This is further enforced by the fact, that, almost as soon as Logan resigned, Hunt began to endeavor to overturn the work of the survey and the teachings of his previous years. In fact, he has quite recently started on a third crusade, with principles designed to upset all he has written before.†

The only other officials who, before the closing years of Logan's work, bore any prominent part in the study of the older crystallines were a young civil engineer, and two persons whose knowledge of geology had been chiefly acquired by practical cultivation of the soil.

Logan alone then seems to have been the motive power of the survey; and it now is necessary to ascertain in what way and under what influences he was prepared for his geological work.

From Harrington's Life of Logan we learn that the latter was employed in the counting-house of his uncle, in mercantile pursuits, from 1817 until about 1831, when he went to Wales as the business manager of some copper-smelting works in which his uncle was interested. Later, he added to this the business of coal mining. Since he requests his brother to purchase and forward to him "some good work on mineralogy and geology, Dr. Dickson will be able to tell you which are best," we may infer that he not only knew nothing of the subjects of, or the

* See *ante*, p. 458.

† The Origin of Crystalline Rocks. Abstract of a paper read before the Royal Society of Canada, May 21, 1884.

workers in, geology or mineralogy, but also that he, at that time, had no books relating to these subjects, although he was then thirty-three years of age.*

In 1833 he appears to have begun his mineralogical and geological work in an amateurish way; and later to have undertaken to lay down the geology of the "South Welsh Coal Basin" on the maps of the Ordnance Survey. A description of the geological map thus made constituted his first scientific paper, which was read† in 1837, *at which time he was thirty-nine years of age.*

Logan gave up his business in Wales in 1840, proceeded to Canada; and, in 1841, visited the coal-fields of Nova Scotia and Pennsylvania. At the time of his appointment as Director of the Canadian Survey, in 1842, the only scientific papers he had read before any scientific body (only one of which had been published) were devoted to questions relating to the geology of coal; and in their recommendations of him for the directorship De la Beche, Murchison, Sedgwick, and Buckland placed all their emphasis on his skill as a geological surveyor of coal-fields.‡

It can thus be seen that Logan, who was forty-four years old, had reached an age when most men's ideas and methods are fixed, the remainder of their lives being spent in developing them. He was purely a stratigraphical geologist, having had experience only in the study of the well-marked stratified formations. Having then and ever after "only a limited knowledge of chemistry, mineralogy, and palæontology,"§ and, so far as we can learn, no acquaintance with crystalline and eruptive rocks, beyond that acquired in the examination of some dikes in the coal measures, Logan was set at work in a country in which he was brought face to face with some of the most difficult problems with which a geologist has ever had to cope — problems which demanded for their solution a training entirely different from that which he had. Now at the period when Logan began his study of geology, and during much of the time when he was the head of the Canadian Survey, the rival theories of Werner and Hutton were yet bones of contention, in a disguised form, while Lyell's publications were exerting a great influence. If we turn to Logan's early reports on the Canadian geology it will be seen that in the study of the older crystalline rocks he follows Lyell implicitly.

* Harrington's Life of Logan, 1883, p. 50.
† Proc. Brit. Assoc., 1837, VII. (sec.), 83–85.
‡ Harrington's Life of Logan, pp. 126–132.
§ Ibid., p. 397.

The latter held that the foliation planes in all gneisses were the results of stratification and proof of deposition from water — the sediments subsequently having been altered by subterranean heat. Those rocks which had been classed as primary, Lyell called *hypogene*, dividing them into an *unstratified* or *plutonic series* and an *altered* or *metamorphic series*. He also contended that "all the hypogene strata, beautifully compact and crystalline as they are, have once been in the state of ordinary mud, clay, marl, sand, gravel, limestone, and other deposits now forming beneath the waters."*

Following the above views of Lyell we see Logan at the outset giving the name "Metamorphic Series" to the older crystalline rocks, assuming that the planes of foliation were stratification planes; and stating that the "syenitic gneiss" or granite possessed "an aspect inducing the theoretical belief that they may be ancient sedimentary formations in an altered condition." † Such a belief, if simply looked upon as a theory, to be proved or disproved by the light of future evidence to be carefully sought for, would not have done great harm; but such was not the method of the Canada Survey, whose officers never took one step toward ascertaining the correctness of their theoretical belief. Yet we find Logan declaring, in 1863, that the Geological Survey had shown, in 1846, that the Laurentian consisted of "a series of metamorphic sedimentary strata underlying the fossiliferous rocks of the province," Hunt, in 1855, making a similar statement.‡

One who carefully reads the reports of that survey can hardly fail to observe that the entire geology of the crystalline rocks was worked out on the supposition that they were stratified, and that the laws of their relations were those that Logan had employed in the study of coal-fields, a difference in the dip or strike of the foliation being considered sufficient for the establishment of a new geological formation. No examination seems to have ever been made for the purpose of ascertaining the origin and history of the rocks in question.

We will now proceed to examine, a little more in detail, the way in which the Azoic or Laurentian rocks came to be divided into two groups — the Laurentian and Huronian. This division originated in the confounding by Logan of the basaltic volcanic rocks interbedded with the Potsdam sandstone of Keweenaw Point with the basic or greenstone

* Lyell's Principles of Geology, 1833, 1st ed., III. 367, 374, 376; 1834, 3d ed., IV. 280, 281, 292; and all subsequent editions of the Principles and Elements, or Manual.

† *Ante*, pp. 331, 332. ‡ *Ante*, pp. 338, 342.

portion of the Azoic of Foster and Whitney as developed north of Lake Huron. The two series possess nothing in common beyond the fact that both are basic and both carry copper — one in the native state and the other in the form of the sulphide. Instead of admitting that the acidic and basic rocks of the Azoic formed one mixed series of eruptive and detrital rocks, Logan here left the gneissic and granitic rocks in the Laurentian and placed the basic ones in a new series — the Huronian — on account of the known unconformability of the Keweenaw Point rocks with the Azoic. Later Logan admitted *sub silentio* the mistake he had made in uniting the Keweenaw Point rocks with those north of Lake Huron, thereby abandoning the data on which the Azoic was separated into two series; yet he persisted in his two divisions, which from that time forward in reality rested exclusively on a lithological basis.

The publication, in 1863, of a volume ostensibly giving the evidence and data as obtained during the previous years of the survey, but which in reality presented as proved that which had only a theoretical basis, with the evidence largely omitted or disguised, contributed greatly to the overlooking of the previous reports, and the acceptance of this as a correct statement of results obtained, and of the nature of the evidence by which they were supported. This was further aided by the persistent misrepresentations of the facts made by Hunt, as pointed out in the preceding pages. These misrepresentations have been so persistent and glaring that we are compelled to say that we consider that Hunt's "Chemical and Geological Essays," his "Azoic Rocks," and his publications generally, cannot be taken as any authority as to what he or any one else has previously taught or held, until his quotations and statements shall have been carefully compared with the original publications. In this matter we are fully in accord with that which Dana has again and again earnestly claimed.

If we examine the often repeated statement that the Huronian unconformably reposes on the worn edges of the Laurentian and contains the *débris* of the latter, it will be found that in every case in which the rocks referred to these two formations were found in contact in the Canadian district (seven in number), the Huronian, with but two exceptions, is said to be conformable with and to generally pass imperceptibly into the Laurentian. In one of these two exceptions the rocks show mutually intrusive relations, and in the other the Huronian abuts against and runs under the Laurentian.

In all cases in which pebbles and fragments of the Laurentian have been found in the Huronian, they were seen occurring high up in the

latter series, and not forming basement conglomerates. All the other so-called proof of unconformity has been made out of the fact that the strike of the foliation in the two formations when not in contact has been found to be discordant — worthless evidence unless the rocks observed in both formations be proved to be sedimentary and the foliation be shown to be coincident with the stratification. Now if the Laurentian was an old metamorphosed sedimentary formation which had been upheaved and contorted, and on whose worn edges the Huronian had been laid down, the evidence of the fact ought to be overwhelming in amount after the country has been studied for so many years. Wherever the Primordial is found in contact with the Azoic, the basement conglomerates and the worn edges of the older Azoic are to be found, and a like condition should be observed if the Huronian is distinct from the Laurentian. But such is not the case, even Selwyn going so far as to declare that the supposed unconformity cannot "be said to be based on or in accord with the stratigraphical observations of either Logan, Murray, Bell, or myself."*

It is well known that any eruptive rock so soon as it comes in contact with erosive agencies will yield fragmental material even before it is cold, and that much eruptive matter is ejected in a fragmental state, so that in a mixed series of eruptive and detrital rocks nothing is more common than to have the *débris* of one enclosed in another, without that enclosure proving that the rocks differ in geological age. This is well known to be the case with the copper-bearing rocks of Keweenaw Point, and it has been shown that the iron ores of the Marquette district, which form a constituent part of the so-called Huronian, are overlain by a conglomerate containing the *débris* of the former — yet both are by every geologist placed in the same series.

The basis of fact which forms the main support of the twofold division of the Archæan — including under that designation all rocks lying below the lowest fossiliferous series — is this: the axial or eruptive portions of disturbed and mountain regions are largely granitic and gneissoid in character. These granitic, granitoid, and gneissic masses are brought to light in the cores of great mountain chains, where long-continued uplift of the original crust of the earth has, through a succession of geological ages, been furnishing the material from which the sedimentary formations were built up. That the gneissic or gneissoid rocks are closely allied to the distinctly granitic and not necessarily metamorphosed stratified deposits is clear to us, as the result of long-continued investigations

* Notes on the "Life of Sir W. E. Logan," 1883, p. 3.

in regions where rocks of this kind occur. Not that all gneisses are of this character; but those are ordinarily so which with granite make up the axial masses of disturbed regions. That the parallel structure of the materials forming gneiss is not necessarily the result of sedimentation seems to us clearly to result from that which has been done both in experimental and field geology within the last few years. It cannot be denied that a foliated arrangement or a parallel disposition of the mineral elements of various sedimentary rocks can be, and often has been, induced in them after their deposition, and that this parallel arrangement is not by any means necessarily coincident with the planes of stratification. This fact alone is absolutely conclusive in favor of the idea that parallel arrangement of the mineral constituents of a rock — in other words, a gneissic structure, in rocks of the granitic family — is not proof of sedimentation.

Overlying the granitic and gneissic axial rocks we are likely to find — and in many cases do find — the stratified masses which were formed from the pre-existing crust themselves usually highly metamorphosed, because formed at a period of great chemical and mechanical activity. With these stratified and highly altered masses are associated eruptive materials — both interbedded and injected in dike-form — these also often greatly metamorphosed, and to such an extent that their original character is only with difficulty, and with the aid of the microscope, to be recognized. This protrusion or forcing out of eruptive materials seems to have followed the preceding uplift of the original crust, if not as a necessity, at least as something extremely likely to occur, as is shown by the fact that in so many great mountain chains we find volcanic activity more and more predominating with the progress of geological time. Since these eruptive materials come from a gradually increasing depth below the surface of the original crust, they are more basic than this, and, since as a rule they contain more iron than that crust, are darker-colored than the masses by which they are directly underlain. Hence the detrital beds formed from the *débris* of these more basic materials are themselves of a dark color, and as a result of their metamorphism we have the various slates, argillaceous, talcose, and chloritic, which so commonly rest upon the granitic and gneissoid rocks which form the core or axis of the disturbed region. With these slaty rocks are also associated limestone masses, which — so far as our observations go — are not ordinarily interstratified with the slates, but are of the nature of segregated deposits, having been formed posterior to the formation of the sedimentary beds with which they are asso-

ciated, while the metamorphic agencies were at work making over the beds into the crystalline form in which we now see them. Similar results have here and there been produced, although not on so grand a scale, during the succeeding geological ages, as we see exemplified in the veins and segregated deposits of later times, which are so well known to those who have occupied themselves with the study of vein phenomena. That these segregated masses of calcareous materials, which occur as veins and which are often metalliferous, are the result of organic agencies, no one who has studied them with care has ever for a moment supposed; and, as has been already stated, we believe that all the evidence is strongly in favor of the idea that the calcareous masses of the Azoic are also deposits from aqueous solution without the intervention of living organisms.

Pursuing the investigation still further, it is seen that the efforts of Logan to apply the principles of his stratigraphical geology to the crystalline rocks led naturally to the adoption of supplementary principles in order to sustain the sedimentary character of the rocks and to aid in their identification. Since the two series could not be distinguished by palæontological evidence, it became necessary to uphold the idea that lithological characters could take the place of palæontological ones as a basis for the arrangement of rocks in chronological order, and their division into groups. But this required that a still more important step be taken, — namely, to insist that all crystalline rocks were of Azoic age and that all non-crystalline detrital ones were Palæozoic or later; and this principle is now openly or tacitly assumed in all work in which the Canadian methods are followed. To say that crystallines necessarily differ in geological age from the non-crystallines, is equivalent to claiming that the crystalline lava that has flowed from Vesuvius is not of the same geological age as that of the ashes and mud which preceded and followed its eruption; for such we have found in some districts to be the exact relations of the older crystallines to the non-crystallines. Furthermore, it is now known that fossils occur in Scandinavia, Belgium, California, and elsewhere in crystalline rocks, — as, for instance, *ammonites* in greenstones.

In the application of their principles the Canadian Survey found it convenient to still further differentiate the rocks that had been classed with the Laurentian and the Huronian, and especially with the latter, since these are in part eruptive, in part detrital, and in part probably segregated deposits, so that their entire conformability with one another could not be expected. The first to be thus separated were the coarsely

crystalline basaltic rocks, or the gabbros, which, on the "theoretical belief" that they were stratified, and on account of their cutting across the strike of some of the limestone belts — as any eruptive mass naturally would — were placed in a system newer than the Laurentian proper. Subsequent investigations have shown that these gabbros are — in part, at least — interbanded with the Laurentian limestones, so that they must be of the same age as those limestones, or else later intrusions. That they are eruptive rocks is the testimony of the present director of the Canadian Survey, and is in accord with the investigations of the best petrographers the world over; while our own investigations in the Adirondacks have led us to similar conclusions. Moreover they have been found by us occurring in dikes in the granite of Eastern Massachusetts.

Further, the Hastings series, although at first looked upon as conformable with and said to pass gradually into the Laurentian, was, on account of its having limestones associated with it and in conformity with the earlier results of Vennor, placed as an overlying formation. Vennor's work, however, having been continued ten years longer, appeared to demonstrate that the Hastings series was continuous with a lower portion of Logan's Laurentian. But Hunt, accepting the earlier work and ignoring the later labors of Vennor, has made out of the Hastings schists and granites the Montalban, and out of the limestones and quartzites the Taconian.

Again the felsites (orthopyres, petrosilex, etc.), which are known to be the old representatives of the modern rhyolitic lavas, and like them to occur in dikes, or to take the form of lava-flows, ashes, etc., and which were first united with the Huronian, have now been erected into a separate series — the Arvonian.

Only lithological principles are now used in making these divisions, and every fact pertaining to the origin and relations of these rocks is ignored; and since, while it is assumed that all these rocks are sedimentary, they were found to occur in dikes and other eruptive forms, it became necessary to hold that all eruptive (including volcanic) rocks were the products of a metamorphic (aqueo-igneous) action. Hence it was claimed that all these rocks had been deeply buried and then denuded,* and most extravagant views became current regarding denudation.

It thus came about that the coarser-grained granitoid and gneissic rocks were set apart as Laurentian; the gabbros and some of the more

* Advocated by Lyell in 1833 and later.

coarsely crystalline diabases and diorites were erected into the Norian; the felsites and quartz porphyries were placed as the Arvonian; the finer-grained diorites, diabases, melaphyrs, and chlorite schists were formed into the Huronian; the more friable granitic and gneissic rocks with the mica schists were classed as Montalban; and the quartzites, limestones, and argillites were united into the Taconian. Of course in each case the metamorphic fragmental forms of each rock were placed with the rocks they resembled, while the other forms of crystalline rocks were distributed through the groups. We give below these arrangements in a tabular form; and in order to aid those geologists who believe in the lithological subdivision of the crystalline rocks into geological formations, we would propose another arrangement, which will be still more in harmony with their views. Thus we would place all the granites, gneisses, and syenites in the Laurentian; erect the magnetites, menaccanites, hematites, and their associated jaspilite into a new series; do the same for the peridotites, including the serpentines; but leave the Norian, Arvonian, and Huronian as they now stand. Further, we may place the porphyrites in a new group; limit the name Montalban to the mica schists, and the Taconian to the limestones; and place the quartzites, conglomerates, and argillites in three additional and distinct groups. All these divisions can be supported by quite as satisfactory evidence as that on which the formations now accepted are sustained. For instance, there is indubitable evidence that the Marquette iron ores are unconformable with the Huronian; the segregated limestones with their associated rocks; the eruptive peridotites, and the resulting serpentines, with theirs, etc.

Present Chronological Arrangement of the Crystalline Rocks.

Coarse-grained Trachytic Rhyolitic Rock.	LAURENTIAN.	Coarse-grained compact Granites and Gneisses.
Coarse-grained Basaltic Rock.	NORIAN.	Gabbro, and some Diabases and Diorites.
Compact Rhyolitic and Jaspilitic Rocks.	ARVONIAN.	Felsite, Petrosilex, Quartz Porphyry, Jaspilite.
Fine-grained Basaltic Rocks.	HURONIAN.	Diorite, Diabase, Melaphyr, Chlorite Schist.
Trachytic and Metamorphic Rocks.	MONTALBAN.	Friable Granites, Mica Schists.
Metamorphic Rocks.	TACONIAN.	Quartzites, Limestones and Argillites.

Proposed Chronological Arrangement of the Crystalline Rocks.

LAURENTIAN	Granites, Gneisses, and Syenites.
SIDERIAN	Magnetite, Hematite, Menaccanite.
OPHIAN	Peridotites, including Serpentines.
NORIAN	Gabbros, coarse Diabases and Diorites.
ARVONIAN	Felsite, Quartz Porphyry, Petrosilex, Jaspilite.
PORPHYRIAN	Porphyrites.
HURONIAN	Diorites, Diabases, Melaphyrs, Chlorite Schists.
MONTALBAN	Mica Schists.
CRYSTALLIAN	Quartzites, Quartz Schists.
TACONIAN	Limestones.
GLACIAN	Conglomerates.
PELODIAN	Argillites.

It would seem that enough has been given to show that the basis of the subdivisions of the Azoic rocks in Canada was a purely theoretical one, and that Logan's methods and opinions were such, when he commenced the survey, that no different result could have been anticipated. It was just as if a geologist should apply the principles used in studying the undisturbed strata of the Mississippi Valley, or the Grand Cañon, to the elucidation of the structure of Mt. Ætna, and attempt to divide its flows and dikes into distinct geological formations. One may take the utmost care in all his measurements, may count every step from Gaspé to Georgia, and make most beautiful maps and sections; yet, if he is unable to determine the characters of the rocks he is mapping, his work is worse than worthless, for every obscure dike that is met with and every segregated mass of limestone causes a new fold and contortion to be inserted. From the fact that the surface distribution only was sought in the Grenville series — in which the limestones are probably of chemical origin — it would appear to us that no reliance is to be placed on Logan's much vaunted work and sections here, beyond the question of surface distribution; and such seems to be the case with all his and his assistants' work on the crystalline rocks.

The present director of the Canada Survey appears to be sincerely endeavoring to base his work on better methods than those current under Logan's administration. All who are interested in the solution of the difficult problems of Appalachian geology will sympathize with him in these efforts; for, as has been already suggested, that which is done in Canada will, *if well done*, be of great assistance to those working on the south side of the Dominion line.

APPENDIX.

SINCE the first part of this work was put in type, another report on the geology of Keweenaw Point has been published by Professor Irving, in the Third Annual Report of the Director of the United States Geological Survey. The state of our knowledge up to the time of the casting of that portion of the work has been presented on pages 76–157, 482–492. In Irving's report the before-mentioned observations (*ante*, pp. 115, 116, 482–484) of Wadsworth at the Douglass Houghton Falls are accepted and pronounced correct in every particular but one. Irving then acknowledges that the copper-bearing rocks are continuous with the eastern sandstone below the falls; but in order to escape the dilemma in which this places him, he says that below on the stream is a covered space between the true eastern sandstones and those which every previous observer had called such, and that here is the junction between the sandstone and Keweenawan series. This space he said Wadsworth had bridged over in his imagination. To this the latter replied, "that, by digging in the stream and on the banks of the ravine, he had actually traced (not imagined) the relations of these rocks, going from those dipping five degrees up to those dipping twenty-five degrees, and that they were seen to form a continuous super-imposed series, no such cliff as imagined [by Irving] existing between them."*

Irving further claimed that at the junction of the sandstone and traps on the Hungarian River (*ante*, pp. 113–115) the sandstone was a loose piece, or, if not, the basaltic rock surely was, and that the prevailing dip of the sandstone was to the southeast. To this "Wadsworth replied that the dips given in the report [Irving's] appeared to have been taken from the frost-dislocated rock on the sides of the stream, while his [Wadsworth's] were taken in the bed of the stream, when the

* Science, 1884, III. 553.

water was exceptionally low. He further stated that the sandstone at the junction was continuous with that seen below; that it extended across the stream and into the banks on both sides; while the baking and induration of it showed that it must have been overflowed by some heated rock. Again: the basaltic rock extended across the stream into both banks, and was found to underlie the conglomerate, and that he dug the *débris* of the former out of the overlying base of the latter. All this, he said, showed conclusively that these rocks were *in situ*, and proved that here the eastern sandstone and Keweenawan series were one and the same; also that this series could not be maintained, as first established."*

Irving further denies the general correctness of Wadsworth's previously published statement relating to the sandstone quarry near Torch Lake (*ante*, pp. 117, 118), and maintains that, while he (Irving) finds traces of the trappean material in the sandstone, he does not find any of the porphyry material belonging to the conglomerates of the "Keweenawan series." This claim proves too much, for if this sandstone had been deposited against the mixed lava flows and detrital rocks of the copper-bearing series as Irving holds, and made up of their ruins, there the sandstone should be full of their *débris*, and the old rhyolitic and trachytic material ought to be far longer retained than the more easily perishable basaltic material; since even in the sandstones intercalated with the traps the basaltic *débris* is comparatively rare. Now Irving's statements are directly opposed to his own views; and the same may be said of the testimony of all those who claim that the sandstone near the traps is composed of different materials from those of the detrital rocks of the so-called Keweenawan series.

Wadsworth has since re-examined the specimens in the collection made with express reference to retaining the evidence in behalf of his previous statements, (*ante*, pp. 117, 118,) and he reiterates those statements with the exception of this correction, that on page 117, third line from the bottom, the word *felsitic* is misprinted *feldspathic*, as the context shows. He finds in these specimens an abundance of the bipyramidal quartz peculiar to ancient and modern rhyolitic rocks, and also the variation between the bedding planes and jointing, both being evident in the hand specimens. The previous statement (*ante*, p. 488), that Irving had adopted Wadsworth's view that the pebbles of the Keweenaw conglomerates were largely old rhyolites and trachytes, Irving denies, since the director of the U. S. Geological Survey had misstated

* Science, 1884, III. 553.

his (Irving's) views.* Irving, in his claim that in "the Keweenaw series occur, as I was the first to announce, so far as I am aware, original masses, not only of basic but also of acid eruptives, and of eruptives of intermediate acidity, the various kinds constituting a continuous series from the most basic to the most acid," * is incorrect, since all this was distinctly announced some thirty years before in the Report on the Copper Lands by Foster and Whitney (1850, pp. 58, 59, 70, 71, 78, 79) in the language of the science of that time.

In the Third Annual Report before referred to, Irving further incorrectly states that Foster and Whitney regarded *all* the acidic or jaspery rocks as metamorphosed sandstones, and all the conglomerates and sandstones as friction detritus.†

In Irving's report there is further given a description of the microscopic characters of the acidic rocks of the "Keweenawan series," in such a manner as to lead any one not conversant with the history of the subject to suppose that Irving was the first to make such an examination, although he was perfectly well aware of Wadsworth's previous labors in that direction (*ante*, pp. 113–112).

Attention has been previously called to his proceeding in the same manner in reference to the Marquette rocks (*ante*, pp. 497, 498). This statement was, however, met by Irving in a sophistical and misleading manner, and by a denial the correctness of which we do not grant. Later, Irving appears to have tried to correct his former injustice to the best of his ability.‡

Nothing appears in the recently published first and third volumes of the final report of the Wisconsin Survey calling for any modification of the earlier part of this work, since one volume is devoted to a theoretical discussion of assumed data, and in the other all the Azoic areas contained only one of the divisions of such rocks made by the Wisconsin geologists, and they are assigned to such divisions on lithological evidence only.

* Amer. Jour. Sci., 1883 (3), XXVI. 321, 322.

† Foster and Whitney, Copper Lands, 1850, pp. 58, 59, 70, 71, 78, 79, 103, 109.

‡ Amer. Jour. Sci., 1883 (3), XXVI. 321, 322; 1884, XXVII. 130–134.

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